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THE PHYSICAL ENVIRONMENT OF AN ABANDONED STRIP-MINE NEAR CADOMIN, ALBERTA

BY

© JOHN DAVID ROOT

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF GEOGRAPHY

EDMONTON, ALBERTA

SPRING 1973

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, a thesis entitled "The Physical Environment of an Abandoned Strip-Mine near Cadomin, Alberta", submitted by J.D. Root, in partial fulfillment of the requirements for the degree of Master of Science.

ABSTRACT

Approximately 350 acres of land were disturbed by the mining operation at Cadomin, Alberta, and no effort was made to reclaim the area apart from removing buildings. The site has remained unchanged since operations ceased in 1952 and thus presented an opportunity to examine the effects of long-term natural revegetation, and potential slope stability and erosion problems. The objective of the study was to determine the geologic and microclimatic conditions that account for the distribution and amount of natural revegetation of the abandoned coal mine southeast of Cadomin. The topography, vegetation, surface drainage and spring discharge were mapped and three microclimatic stations were installed in the minesite and two in the adjacent undisturbed area. Air, surface and soil temperature, humidity, precipitation and wind speed were recorded at each station from June to September 1972. The spoil materials consist of fractured sandstone, shale, coal and minor conglomerate and ironstone of the Luscar Formation. These materials, especially the shale and softer sandstone, weather extremely rapidly and this weathering can be attributed primarily to frost-wedging. Despite the steep slopes typical of the spoil piles and the availability of comminuted material little degradation by mass wasting occurs. The occasional rockfall and debris fall do occur but talus creep and rock creep are the dominant mass-wasting processes. Spoil material is transported by running water and gullies have resulted; this erosion is relatively minor as runoff is minimal because of removal of snow cover by high winds and the high spoil permeability. Spoil piles observed in the Cadomin area are therefore stable. Chemical analysis of surface

water above the minesite and spring discharge below and in the minesite indicate little change in total dissolved solids or chemical constituents of the water. This indicates rapid movement of water through the spoil and minimal chemical reaction of the water with the spoil. Observations and measurements indicate that seed supply, soil moisture and high winter winds are the three dominant factors that account for the minesite's natural revegetation. The prevailing wind from the west is strong and persistent and transports seed over the mine, dropping seed only on the lee sides of boulders or mounds, or in depressions and this results in an extremely azonal and sparse vegetation. Vegetation growth is inhibited by the inability of the spoil material to retain moisture; fines and organic material are lacking on the surface and infiltration of water is rapid. Potential evapotranspiration is significantly higher in the minesite than in the control area and a greater moisture deficiency exists in the minesite for longer periods than in the control area. Vegetation growth is further inhibited by abrasion by wind-blown snow and rock particles during winter and dessication during chinooks. The vegetation distribution therefore reflects the areas that are protected from wind, that have adequate soil moisture supply or spring discharge, and have snow cover during winter.

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Sincere thanks are offered to my supervisor, Professor R. W. Longley, whose exacting demands, enthusiasm and critical eye have taught me so much.

I am indebted to Dr. L. A. Bayrock of Bayrock Surficial Geology Ltd. for the recognition, encouragement and support he has given me over the past few years and to Dr. G. B. Mellon, Head of the Geology Division of the Research Council of Alberta who has given much practical advice and guidance.

My wife Judy identified the plants present in the study area, typed the manuscript and helped me in innumerable ways.

Mr. Tom Dillon provided useful data on the Luscar minesite and much fruitful discussion.

The Research Council of Alberta funded the field work and Mr. Gerry Lobb and Mr. Conrad Kathol provided excellent field assistance. Mr. Pfanmuller of Inland Cement Industries Co. Ltd. generously allowed the use of the Company's bridge across the McLeod River at Cadomin.

The Atmospheric Services Branch of the Canada Department of the Environment, the Hail Studies Division and the Geology Division of the Research Council of Alberta, and the Division of Meteorology, University of Alberta provided various instruments for the study.

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CHAPTER I

INTRODUCTION

General statement

Coal has been extracted in the Alberta Foothills since the late 1800's, and economic, technological and social conditions have changed significantly since then. The present shortage of fossil fuel energy and the stringent regulation on sulphur content of fossil fuels is opening up new markets for Alberta-Foothill coal. At present, this coal is most economically extracted by surface mining as the use of giant and automated machinery is cheaper than labour-intensive, relatively dangerous, underground mining. The operating mines at present are therefore much larger and disturb much more land than any past mining operation. Until a few years ago it was considered acceptable to abandon minesites without any attempt to reclaim the landscape. Today the public has recognized values of landscape other than the economic benefit of mineral extraction and has demanded the reclamation of land disturbed by mining. The Alberta government has recognized public concern and has passed laws to require reclamation of land disturbed by surface coal mining. Unfortunately although there is much established knowledge on the reclamation of disturbed land in Europe and the eastern U.S.A. there is little similar knowledge for the Alberta Foothills.

An estimated 32,000 acres of the Alberta Foothills will be strip-mined for coal over the next 20 years. This estimate excludes areas utilized for access roads, service facilities, townsites and coal exploration activities; thus a significant area ultimately will require

reclamation if it is to be restored to a condition approximating its former state. Reclamation is usually interpreted to mean restoring the disturbed area to its original contour, ensuring stable slopes, and preventing erosion and physical and chemical contamination of water courses by revegetating the disturbed area. Although the restoration of disturbed land to stable, if not the original contours, presents no difficulty, the remaining aspect of reclamation, especially revegetation, presents considerable difficulties, and at present, successful reclamation procedures in the Alberta Foothills remain to be determined.

The abandoned minesite at Cadomin was visited in October, 1971, and the writer's observations and conclusions suggested that micro-climatic and geologic conditions regulate the area's natural revegetation.

Objective

The objective of the following study was to investigate and determine the geological and microclimatic conditions that account for the distribution and amount of natural revegetation of the abandoned coal minesite southeast of Cadomin, Alberta.

Location of and access to the study area

The study area is situated in the foothills region of west-central Alberta at 53°01' north latitude and 117°18' west longitude (Figure 1). The study area is 1.6 km southeast of the town of Cadomin which is accessible from Hinton (48 km to the north) via Luscar and from Edson (112 km to the northeast) via Highway 47. The study area is accessible from Cadomin by the bridge owned by Inland Cement Industries Company Limited across the McLeod River. A road from the bridge runs parallel to the river and 2.7 km north of the bridge the road connects with the abandoned haul road to the minesite.

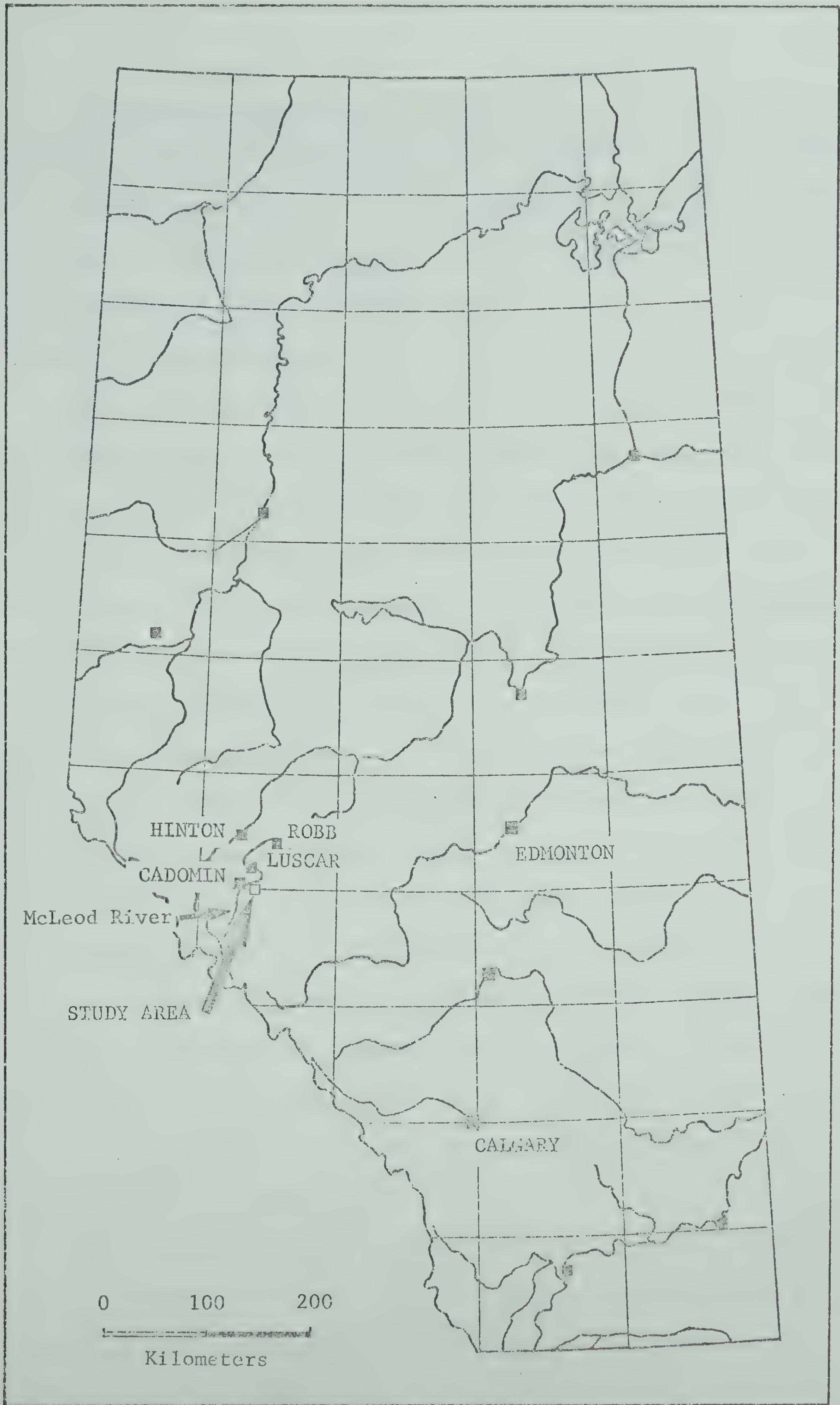


Figure 1.1. Location of the study area.

The study area consists of all land disturbed by the mining operation (350 acres) and the adjacent, undisturbed land surrounding the area (300 acres) (Figure 1.2). All disturbed land will be referred to as the "minesite" and all undisturbed land surrounding the minesite will be referred to as the "control area".

Physiography of the region

The study area lies at approximately 1675 m above mean sea level, just below treeline at the extreme eastern edge of the Rocky Mountains on the northeast flank of the Nikanassin Range. Peaks in this range are up to 2438 m high. The range extends 30 km to the northwest and 27 km to the southeast from Cadomin, and is cut by the valley of the McLeod River about 1.6 km west of the study area. The range represents a considerable barrier to the easterly flow of Pacific air. The McLeod River has eroded the valley floor to 1525 m above mean sea level and the flow of air through this gap is often rapid and violent and has given rise to the awesome high winds recorded at Cadomin. The effects of these winds will be discussed in the following chapters.

The study area is bounded on the northwest by the McLeod River valley and on the southwest by the Nikanassin Range. To the northeast a small valley separates the study area from a range of foothills 1800 m high which parallels the mountain ranges. To the southeast the study area is bounded by a rounded spur of the Nikanassin Range.

Topography of the minesite

The minesite consists of a large main pit, an upper smaller pit and the overburden material that was dumped downslope from the pits (Figure 1.2). The overburden material dumped downslope consists of the broken rock strata, soil and vegetation that was removed

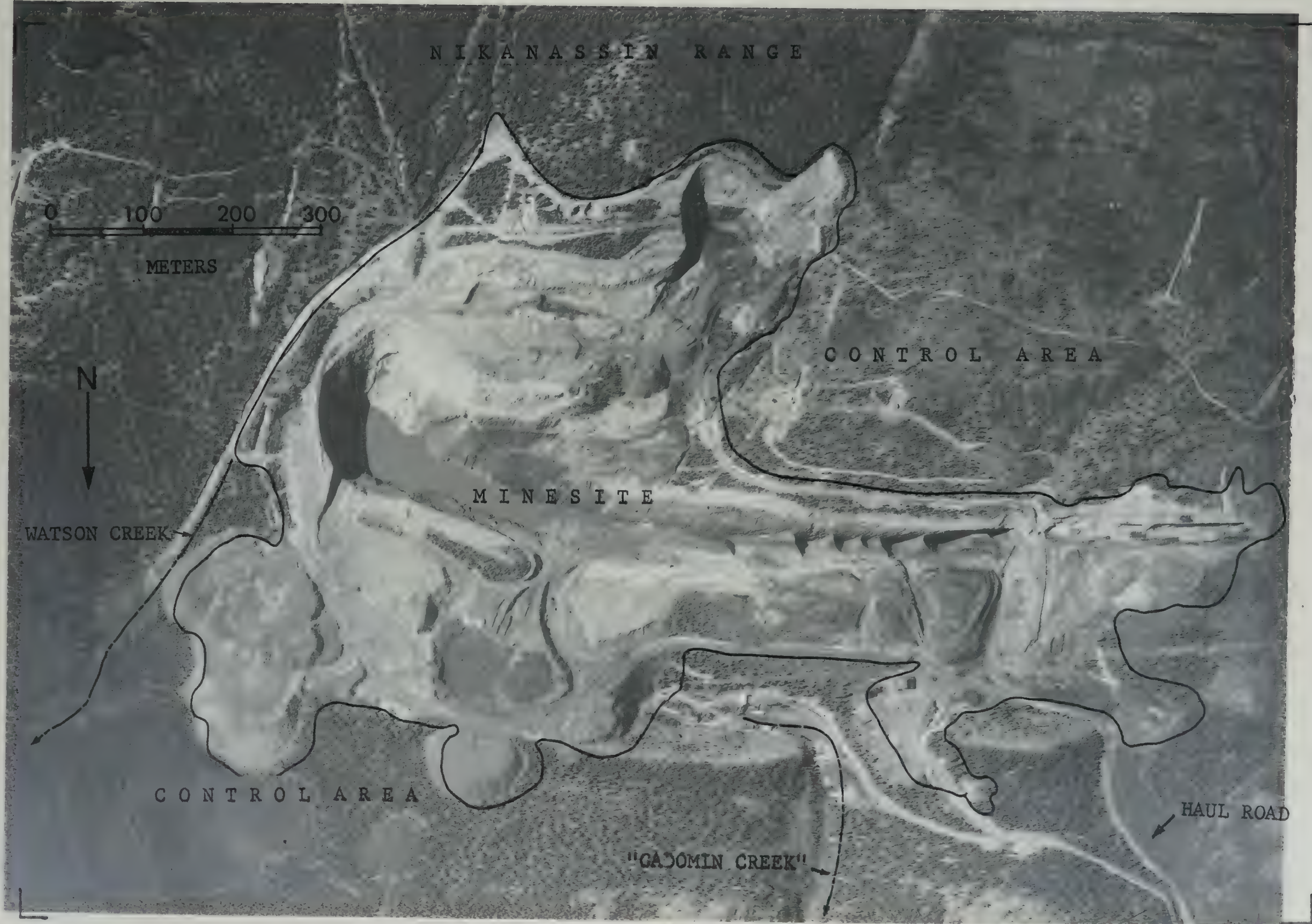
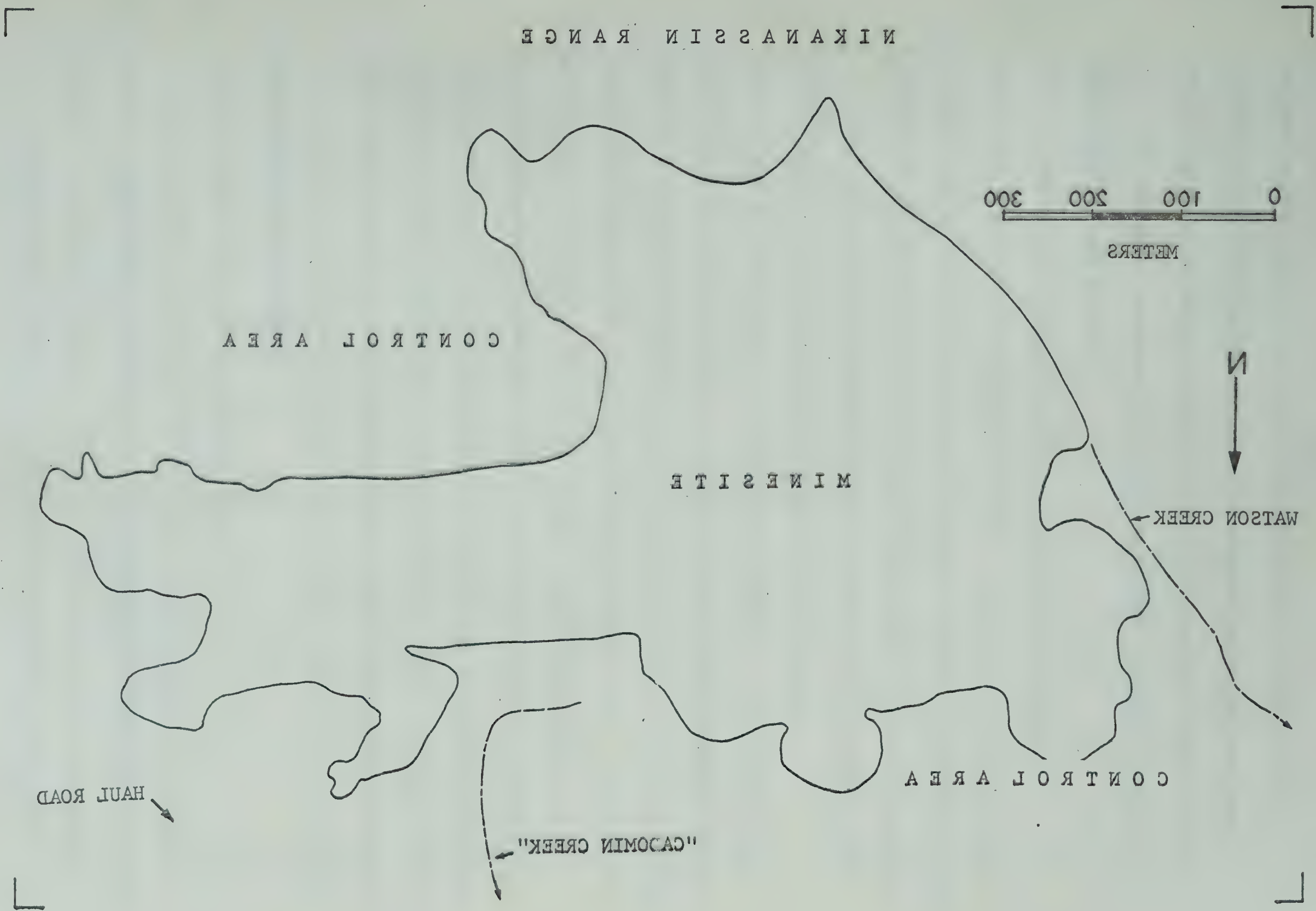


Figure 1.2. Vertical air photograph of the study area.



NIKANASSIN RANGE
0 100 200 300
METERS
N
CONTROL AREA
MINESITE
WATSON CREEK
CONTROL AREA
HAUL ROAD
"CADOMIN CREEK"

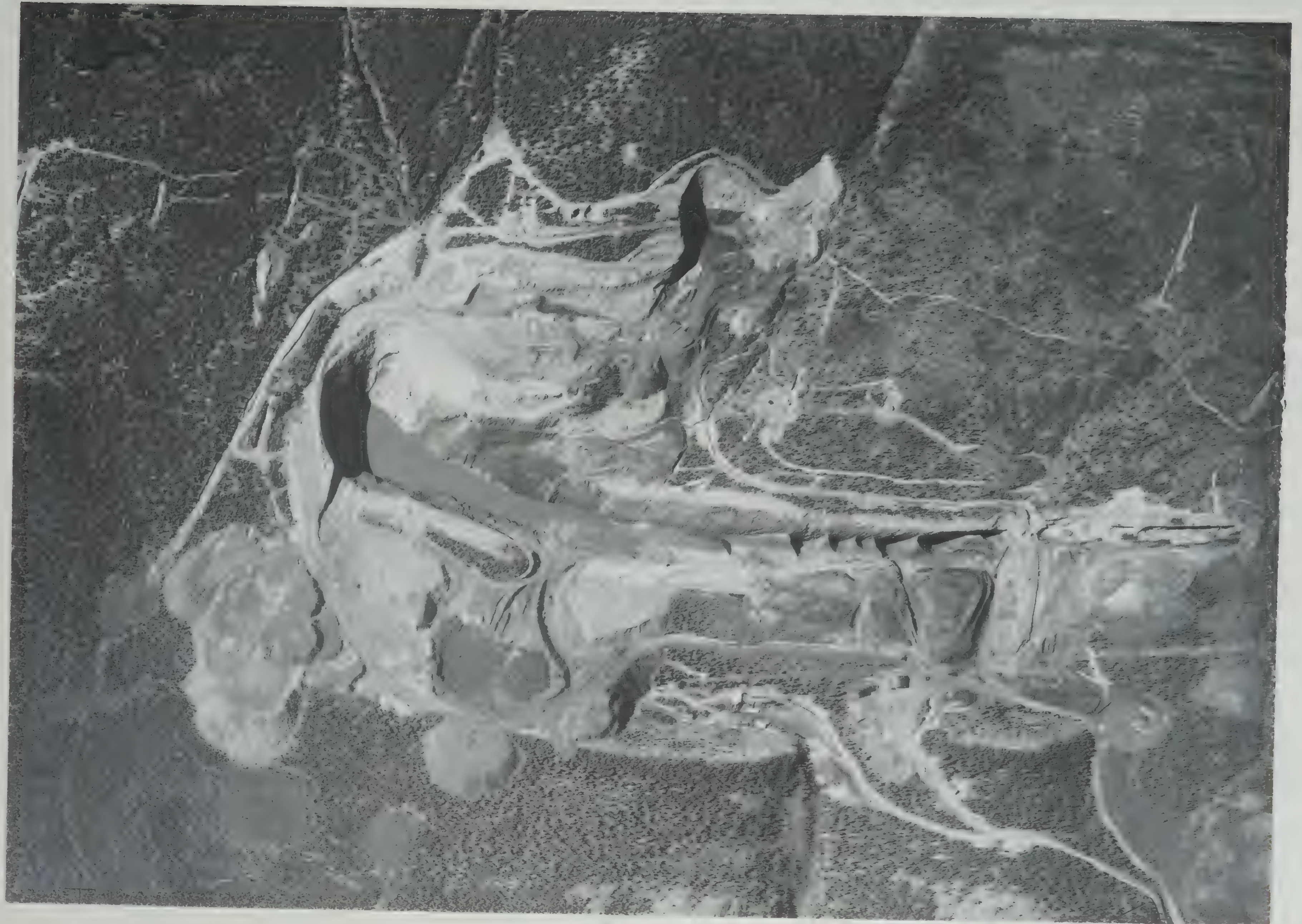


Figure 1.2. Vertical air photograph of the study area.

to gain access to the coal seams. This material forms the characteristic flat-topped and steep-sided lobes which will be referred to here as spoil piles.

The main pit is an elongated tear-drop shape, is 793 m long, 61 m deep at the wide east end and less than 15 m deep at the narrow west end. The walls of the main pit are very steep. At the west end of the main pit the south wall is vertical; the south wall at the east end is not as steep (55 degrees). The north wall in the main pit has a series of stepped cliffs along its length but is not generally as steep as the south wall.

The upper pit is smaller, shallower and has less steep walls than the main pit. The pit resembles a golf club with the club at the west end. It is 240 m long, 60 m wide and 27 m deep.

The spoil piles from the main pit form an extensive flat-topped, steep-sided, tiered benchland at the lower east end of the minesite. A rolling topography with two isolated spoil piles extends between these spoil piles and the west end where one long spoil pile is present. The spoil piles from the upper pit are smaller but are close to the upper edge of the south wall of the main pit (Figure 1.2). The topography of the minesite is thus varied and rugged with a preponderance of steep slopes and flat surfaces.

Topography of the control area

The control area to the west comprises the uniform undisturbed slope of the mountainside. The control area to the north of the minesite contains a steep-sided valley and a low ridge which separates the study area from the main valley below.

Drainage of the study area

The study area is drained by Watson Creek which flows to the east and "Cadomin" Creek which flows to the northwest; both creeks are small but permanent and both flow into the McLeod River.

Climate

The climate of the region is classified as subarctic or Dfc in the Köppen system of climatic classification. The letter D signifies humid microthermal climates with cold winters and short cool summers, the mean temperature of the coldest month below -3°C and the mean temperature of the warmest month above 10°C. The letter f signifies precipitation throughout the year. The letter c signifies cool, short summers with only one to three months with a mean temperature above 10°C (Atlas of Canada, 1957). The climate varies considerably from place to place because of the rugged topography, large local relief and exposure to wind. During the winter months air that passes over the Rockies periodically descends rapidly and warms adiabatically and the chinooks which result lead to high temperatures, rapid removal of snow cover and dessication of vegetation in the area.

Soils

Soils of the region are complex and are dependent on the parent material and elevation. The study area was not glaciated during the Pleistocene and the soils have developed directly from weathered bedrock. The dominant soils of the control area are described as Lithic Orthic Grey Luvisols with Lithic Degraded Eutric Brunisols significant (Research Council of Alberta Soil Survey, 1972). The soils are medium- to fine-textured, light olive brown to yellowish brown, stony and have a thin (2 - 8 cm) organic Ah horizon.

Vegetation

Vegetation in the region is classified as lodgepole pine-white spruce-Engelmann spruce (*Pinus contorta* var. *latifolia*-*Picea glauca*--*Picea engelmanii*) (Atlas of Alberta, 1969).

The vegetation in the control area is mainly Engelmann spruce and white spruce with some lodgepole pine, balsam poplar (*Populus balsamifera*) and alder (*Alnus crispa*). The tree cover is scattered and stunted. Vegetation in the minesite will be discussed in Chapter V.

Reclamation

Approximately 350 acres of land was disturbed by mining operations at the minesite and no effort was made to reclaim the area apart from removing buildings. The study area has remained unchanged since operations ceased in 1952 and thus it presented an opportunity to examine the long-term natural revegetation and potential slope stability and erosion problems.

Previous work

Although voluminous literature is available on many aspects of disturbed land reclamation for the eastern United States and some parts of Europe, little similar literature is available for the Alberta Foothills. Peterson and Etter (1970) have summarized the literature related to disturbed land reclamation and research in the Rocky Mountain region of Alberta and conclude that there is a need to "... define the critical environmental factors which limit ... plant growth on ... disturbed sites". To the writer's knowledge there has been little research conducted on geologic and microclimatic conditions associated with disturbed land in the Alberta Foothills.

The geology of the Alberta Foothills is well known. MacKay (1929, mapped the bedrock geology and described and named the formations present around the Cadomin area. Mellon (1966) described a section of bedrock at Cadomin and this is discussed in full in Chapter II.

Harrison (1972) reported on the "... initial stage of a study of the geological, geomorphological and hydrological factors affecting mountain coal resource exploration, exploitation and subsequent land restoration ... in the Crowsnest Pass-Elk Valley area of Alberta and British Columbia" (p. 184). He examined thirteen surface mines and noted the aspect, profile, stability, associated deposits, composition, active geomorphic processes and vegetation of each. His preliminary analyses concur with those reported by Root (1972). Harrison reports that:

(i) Slopes greater than 30 degrees are rarely revegetated naturally and the downslope creep of surface material is rapid.

(ii) Downslope creep is not sufficiently rapid to regrade steep slopes in an acceptable period of time.

(iii) "Infiltration on most spoil is sufficiently high that run-off is available to form rills and gullies. The exception is where areas of drainage accumulation occur uphill from the spoil. Slope regrading by running water is therefore not an important process." Sic; the word "little" must be inserted between "that" and "run-off" for the first sentence to read correctly.

(iv) Softer rock types break down rapidly by physical weathering and mineralogical and chemical changes at the surface are

minimal.

(v) " ... slope failures are intimately related to moisture usually in the form of water ponded uphill".

Geochemical and sediment samples were also collected but analyses have not been published.

Currie (1969) investigated the hydrogeological conditions of the Tri-Creeks Basin about three miles northeast of the study area. He found a plant association of lodgepole pine, broom grass, and bearberry to be indicative of natural groundwater recharge conditions.

Jacoby (1969) compared the revegetation of coal spoil banks of various ages after modifying the local microclimate with jute netting, snowfences and mulch, but he did not actually measure the microclimate. This work was conducted near Kemmer, Wyoming, and the results may have application in the Alberta Foothills.

Thirgood (1971) refers to disturbed land revegetation and pedologic conditions in the Rocky Mountains of British Columbia, but did not discuss microclimate.

During the summer of 1972 Dillon (pers. comm.) studied seed germination and the associated microclimatic conditions for two small, isolated plots on the spoil piles at the present minesite at Luscar (11.2 km north of the study area) and one abandoned spoil pile adjacent to, and east of the present minesite at Luscar. Half of the area of the two plots at the operating minesite were compacted with a bulldozer and the other half was left uncompacted. A variety of seeds (mainly grasses), an adhesive and a fibrous mulch were applied with a hydroseeder to each of the three plots. Dillon made detailed observations on the germination and growth of the seeds and measured incoming solar radiation,

wind speed, temperature and humidity at 30 cm above the ground surface, surface temperature and soil temperatures at 1 and 5 cm below the surface and used sequential infrared (Ectachrome) photography to determine the moisture stress of individual plants. He concluded that the plant growth was limited to small depressions, that optimal growth of the plants was limited by lack of moisture, and that plant growth was better on compacted spoil material than on non-compacted spoil material. He attributed the lack of moisture to relatively low precipitation and high evapotranspiration promoted by persistent high winds over the study area. Dillon calculated potential evapotranspiration for the Luscar sites and this will be compared with the values for the Cadomin study area in Chapter IV.

Krause (1969) pointed out the need for reclamation procedures to match the local climate and topographic conditions. He observed that "what the land produced before mining is a ... good indicator of what it can produce after mining" (p. 24). He listed topography, erosion, moisture, aeration, and toxicity as key factors in reclamation. He made no mention of microclimate and only passing mention of geologic conditions.

Donald (1969), discussing Kaiser Resources reclamation program for the Crowsnest area of British Columbia, states that "Studies have shown that spoil provides a better growing medium if it is left where it falls, without compaction and with a minimum of contouring and reshaping" (p. 32). This contradicts the findings of Dillon (1972) and shows the significance of local climatic conditions. Prevention of erosion by runoff on spoil will enhance the infiltration and percolation of moisture whereas in the Alberta Foothills runoff over spoil is rare (Dillon, 1972,

pers. comm.; Harrison, 1972).

Berkowitz (1969), discussing surface mining in the Alberta Foothills, states that "At high elevations, where natural plant cover is either absent or scanty and stunted by climate and a rocky (almost soil-less) substrate, reclamation in the commonly accepted sense is clearly impossible" (p. 42).

Present study

To accomplish the objectives stated at the beginning of this chapter the study area was instrumented and surveyed as follows. Five microclimatic stations were established in the study area as soon as instruments became available in early June 1972. Continuous records of air temperature and humidity, and periodic records of soil temperature, surface temperature, air temperature profiles, and precipitation were maintained until September 1972. A topographic survey of the minesite was made using a plane-table and the vegetation abundance and type were mapped. Samples were taken of surface runoff above the minesite, lake water and spring discharge within the minesite and spring discharge below the minesite for chemical analysis. Samples of spoil and wind-blown material were also taken. A snow survey was made over the study area in March and May of 1972 and January of 1973.

CHAPTER II

GEOLOGY

General statement

This chapter will describe the geological formation from which the coal was derived and the geomorphic processes which account for the present surface of the minesite.

All coal extracted from the study area came from the upper beds of the Luscar Formation. This formation was named by MacKay in 1929 and described on the map legend as "shale, sandstone and coal" (Figure 2.1). In 1930 the formation was described as "soft grey sandstone and dark grey shale with commercial coal beds in the upper part" (MacKay, 1930).

The Luscar Formation is underlain by a resistant chert and quartz-pebble conglomerate called the Cadomin Formation and overlain by a coarse green sandstone and green shale with lenses of pebble conglomerate called the Mountain Park Formation (Mellon, 1966). All three formations are lower Cretaceous in age. The three formations are exposed in a railway cut close to the study area and this cut was described in detail by Mellon (1966); the following section follows Mellon closely.

The Cadomin Formation consists of well-rounded white, pink, grey and black quartzite, chert and silicious argillite pebbles up to 15 cm in diameter in a grey, silica-cemented sandstone matrix. The unit is thin (10.7 m) and fewer pebbles are found in the upper 3 m. (Mellon would include this formation as the basal member of the Luscar Formation). The lower succession of the immediately overlying Luscar Formation consists of dark grey silty shale, laminated siltstone and thin-bedded, fine-grained, dark grey sandstone with scattered coal seams

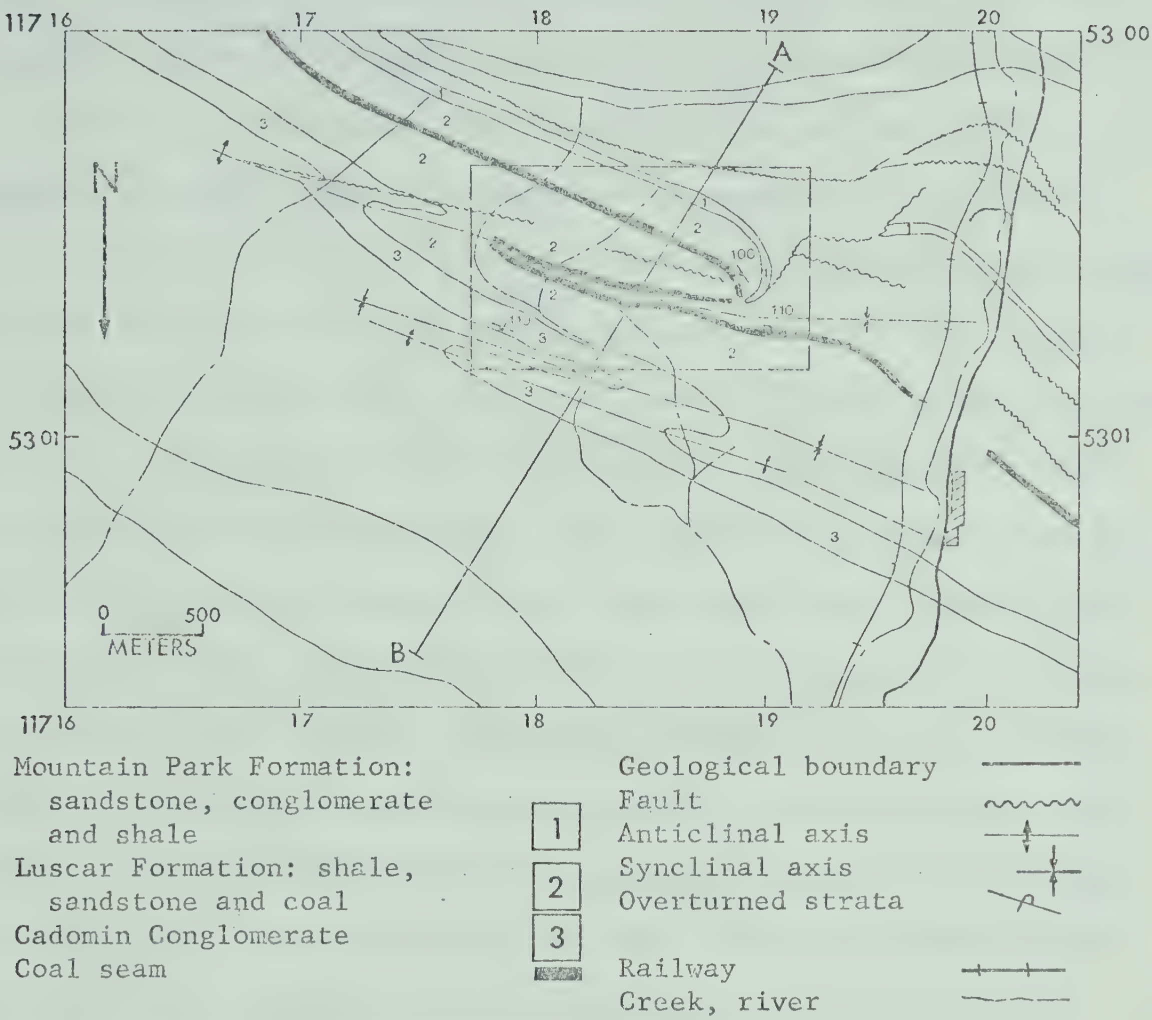


Figure 2.1. Bedrock geology of the study area (after B. R. MacKay, 1929).

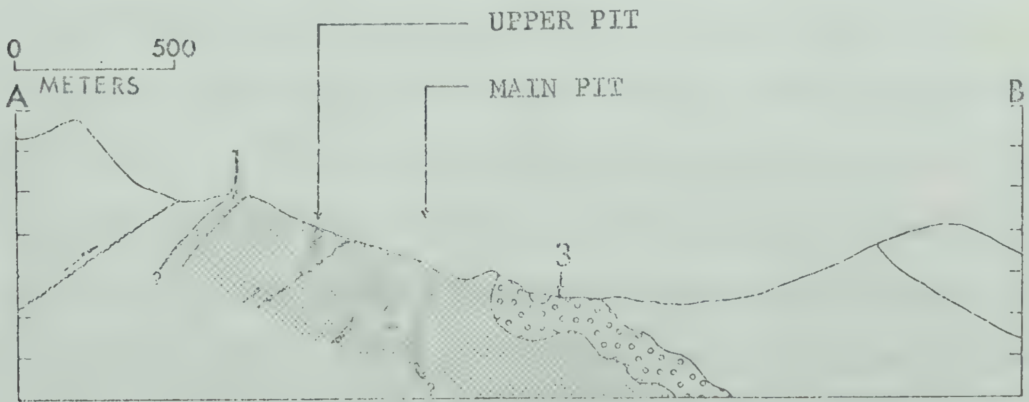


Figure 2.2. Cross-section through the study area. Drawn from map by MacKay (1929).

30 - 60 cm thick. The lower Luscar beds are mainly dark grey fine-grained sandstone and laminated siltstone intervals up to 7.6 m thick which are separated by black, silty shale and shaly coal beds from 0.3 - 1.5 m thick. These sandstones are tough, fine-grained silicious rocks composed of quartz, chert, silicious rock fragments and carbonates. Above these lower Luscar beds a bed of marine dark-grey, non-silty shale with scattered thin ironstone nodules or beds are found. This bed is overlain by the upper Luscar beds which consist of two, thick, grey sandstone beds which sandwich the 8.4 m thick coal seam (the Jewel seam) which was mined in the study area. The sandstones above and below the Jewel seam are grey, medium-grained, cross-bedded and relatively homogenous units. The lower sandstone contains small amounts of feldspars and volcanic rock fragments and the upper sandstone contains abundant amounts. Kaolinite and quartz are the dominant cements in both sandstones. The upper Luscar beds grade into the overlying Mountain Park Formation which consists of silty and shaly strata with fine-grained sandstone. The coal-bearing upper Luscar beds may be traced as far south as the Ram River and as far north as northeastern B.C. and thus, if coal is extracted from this formation elsewhere in this region geologic conditions similar to that of the study area will arise.

The bedrock materials immediately adjacent to the coal seams are removed during the course of surface coal extraction and thus the spoil piles are comprised of these materials. The spoil piles consist of large to fine, broken, angular fragments of grey, medium-grained, cross-bedded sandstone which contain various amounts of feldspar and volcanic rock fragments, shale, siltstone, conglomerate and coal. The approximate proportions are shown in Table 2.1 but it should be noted that the percentages vary considerably from spoil pile to spoil pile.

Table 2.1. Estimated percentages of bedrock types in spoil piles

Bedrock type	Proportion of spoil in %
Sandstone	50 - 75
Shale and siltstone	30 - 50
Coal	5 - 10
Ironstone	4 - 10
Conglomerate	1 - 2

The attitude of the coal seam is shown in Figure 2.2. At the west end of the study area the coal seam is nearly vertical and is shown on MacKay's map as being overturned at 110 degrees (Plate 2.1). At the east end of the study area the coal seam formed an anticline (with the arch eroded) with the west limb repeated further upslope by a thrust fault. The mining process consisted of diverting the two creeks in the study area around the minesite, blasting the bedrock, removing the overburden and dumping it overslope and extracting the coal. The seams were nearly vertical and considerable bedrock had to be cut back to maintain stable highwalls and coal extraction was limited by the cost of cutting the bedrock walls back to stable conditions. Thus large spoil piles developed downslope from the main pit.

Weathering

Rapid weathering occurs at the surface of the minesite in the study area and this may be attributed to frost wedging, abrasion by wind-borne particles, swelling and shrinking of the clay cement on wetting and drying, solution of the carbonate, kaolinite and quartz cements of the sandstones and the release of overburden pressure after mining. In

places protected from the wind, angular piles of loose sand from the disintegration or exfoliation weathering of boulders may be observed and where sandstone boulders are exposed in the steep slopes of spoil piles exfoliated loose sand streaks the spoil downslope from the boulders (Plates 2.6 - 2.9 and 2.11). A sandstone boulder at one location had a weathered rind of 100 mm and weathered rinds of 20 mm were common (Plate 2.8). Since the boulder could have been exposed for only 20 - 40 years the thickness of weathered rind indicates a rapid rate of weathering.

Spoil materials exposed to the atmosphere at the adjacent minesites at Luscar 11.2 km north of the study area have been observed to weather extremely rapidly (R. Green, pers. comm.; T. Dillon, pers. comm.).

Most of the spoil materials have disintegrated to angular, blocky fragments (Plates 2.3 - 2.5 and 2.9). The thin ironstone beds form almost perfect cubes and the more competent shales and siltstones form flaky elongated, irregular diamond shapes (Plates 2.3 and 2.5) Conglomerate bedrock and some tough sandstone remain unaltered in angular, blocky fragments.

Coal fragments up to 60 cm in diameter may be found mixed in with the surface materials but most of the coal has weathered to weak, flaky clods. The surface of many of the exposed shale boulders have weathered to acicular and small, platy fragments which may be dislodged easily and collapse freely (Plate 2.4).

The blocky shape of the disintegrated spoil materials indicates that physical weathering is primarily responsible (Ollier, 1969, p. 17) (Plate 2.5). The cold, dry, climate and the short period of time elapsed since the materials were exposed to the atmosphere preclude significant chemical weathering.

The insulating snow cover is removed from many places in the mine-

site by the high persistent winds and this results in more frost shattering and abrasion by wind-blown particles than in the control area which is sheltered from the wind by vegetation and retains fallen snow. The high winds that blow over the minesite remove the finely-comminuted rock material, the finest particles are uplifted and the larger particles moved by saltation or rolled along until they escape the wind in snowdrifts or in the vegetation at the east and south end of the minesite. A layer of wind-blown particles 7 - 20 cm thick was found covering a snowbank in the east side of the scarp slope of a spoil pile in June (Plates - 2.20) 2.13 - 2.20) and many thinner layers were recorded in snowbanks during the snow surveys of March 1972 and January 1973.

Mass-wasting

The downslope movement of rock particles under the influence of gravity but without the aid of any transportation medium are limited to rockfalls, rockslides, debris falls, debris slides, and soil and talus creep (terminology of Sharpe, 1960).

A rockfall is defined as the relatively free falling of a newly-detached segment of bedrock of any size from a cliff, steep slope, cave or arch (Sharpe, 1960, p. 78). Rockfalls occur from the south walls of the main pit and the upper pit (Figure 2.3).

A rockslide is the downward and usually rapid movement of newly-detached segments of the bedrock sliding on bedding, joint or fault surfaces or any other plane of separation (Sharpe, 1960, p. 76). The distribution of rockslides is shown in Figure 2.3.

A debris fall is the relatively free falling of predominantly unconsolidated earth or debris from a vertical or overhanging cliff, cave or arch (Sharpe, 1960, p. 75). The distribution of debris falls is

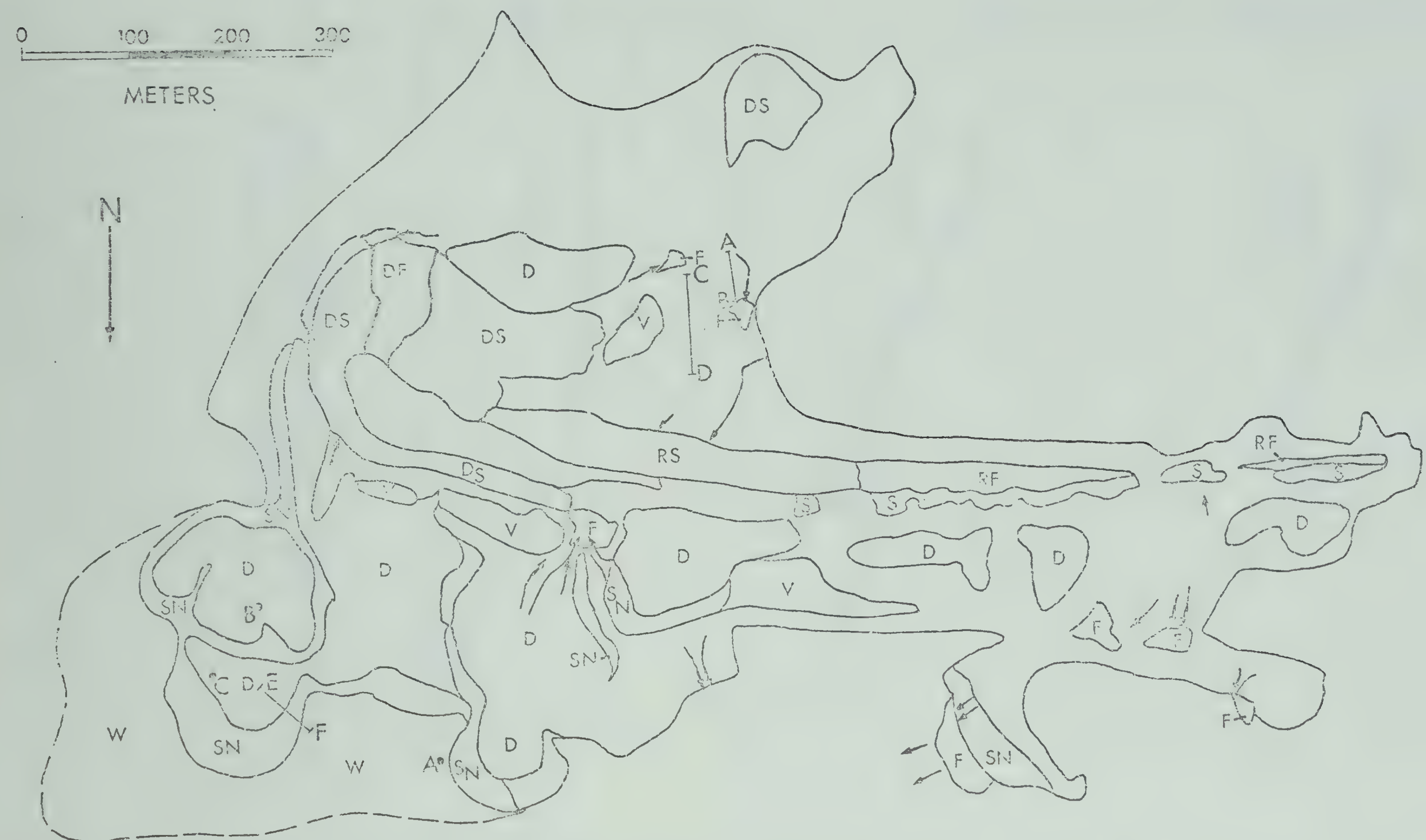


Figure 2.3. Rockfalls (RF), rockslides (RS), debris falls (DF), debris slides (DS), subsidence (S), deflation areas (D), rock particle accumulation areas (W), snowbank accumulation areas (SN), undisturbed vegetation areas (V), gullies (arrowed line), alluvial fans (F) and sample locations (A, B, C) within the study area.

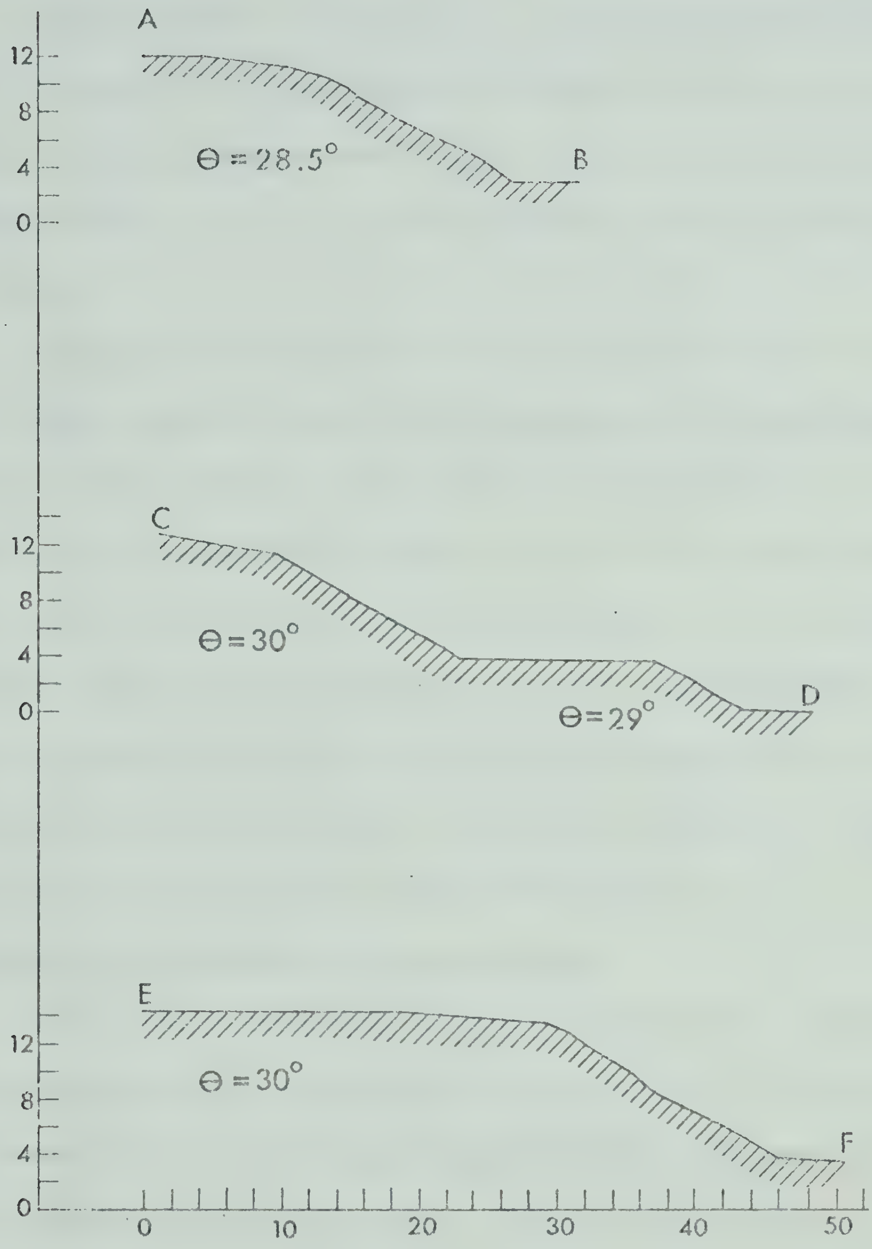


Figure 2.4. Cross-section of typical spoil piles; (no exaggeration, arbitrary datum; see Figure 2.3 for location). Scales in meters.

shown in Figure 2.3.

A debris fall is defined as a rapid downward movement of predominantly unconsolidated and incoherent earth and debris in which the mass does not show backward rotation but slides or rolls forward (after Sharpe, 1960, p. 74). The distribution of debris slides is shown in Figure 2.3.

Subsidence is defined as "movement in which there is no free side and surface material moves vertically downward with little no horizontal component" (Sharpe, 1960, p.88). Subsidence has occurred at the west end of the main pit. Here coal had been removed underground and collapse of the roof followed the removal of the supporting pillars of coal during the final stage of mining. The subsidence forms elongated, steep-sided conical pits up to 15 m deep and 30 m across and where subsidence has occurred immediately adjacent to the highwall the subsidence pits are half-cone shaped (Plate 2.1).

Erosion and deposition by running water

Gullies have developed in the minesite where streamflow previously diverted around the minesite has flowed across spoil material, at the overflow outlet of the upper lake, below various areas that have extensive snowdrift and below springs (Figure 2.3). Gullies, once formed, tend to perpetuate themselves as the incised V-shape prevents snow removal by wind and the accumulation of snow releases a sustained flow on melting during the spring. The surface outlet for the upper lake is across a road which ponds the upper lake and although the lake is rarely high enough to use this outlet, a large gully has developed immediately below the outlet. The gullies themselves vary considerably in shape but are typically very steep sided and relatively short and broad which is

the characteristic shape for coarse-grained material.

Significant material has been removed from these gullies by running water. The gully walls once erodedby flowing water will provide an abundant and continuing source of easily-transported material as the spoil exposed in the gully is weathered extremely rapidly. Considering that runoff is rare, that much of the snowfall is removed and significant snowbanks do not accumulate, that rainfall is recurrent, relatively light and not very often intense, the gullies that exist in the minesite show that the spoil has a high potential for erosion.

Erosion and deposition by wind

The finely-comminuted material is removed from the flat and rounded westerly exposed surfaces of the spoil piles (Plate 2.12). These westerly exposed surfaces have developed a deflation pavement of angular blocks that are too large to be disturbed by the wind (Figure 2.3 and Plate 2.11).

Where large blocks are prominent pebble dunes have formed to the east of these blocks (i.e., in the lee of the block) (Figure 2.5 and Plate 2.11).

Figure 2.3 shows the distribution of wind-blown material removed from the minesite and its source within the minesite.

A sample of wind-blown rock particles from the base of the spoil due west of control station 2 was taken (Sample A) and a sample of rock particles that were uplifted and blown into the screen sheltering the weather instruments at minesite station 3 was collected (Sample B). A sample of wind-shifted material was taken from the pebble dune shown in Figure 2.5 (Sample C). The size of most particles in the dune ranged from 1 to 2 cm and one was measured at 4.5 cm. During the snow surveys cobbles of

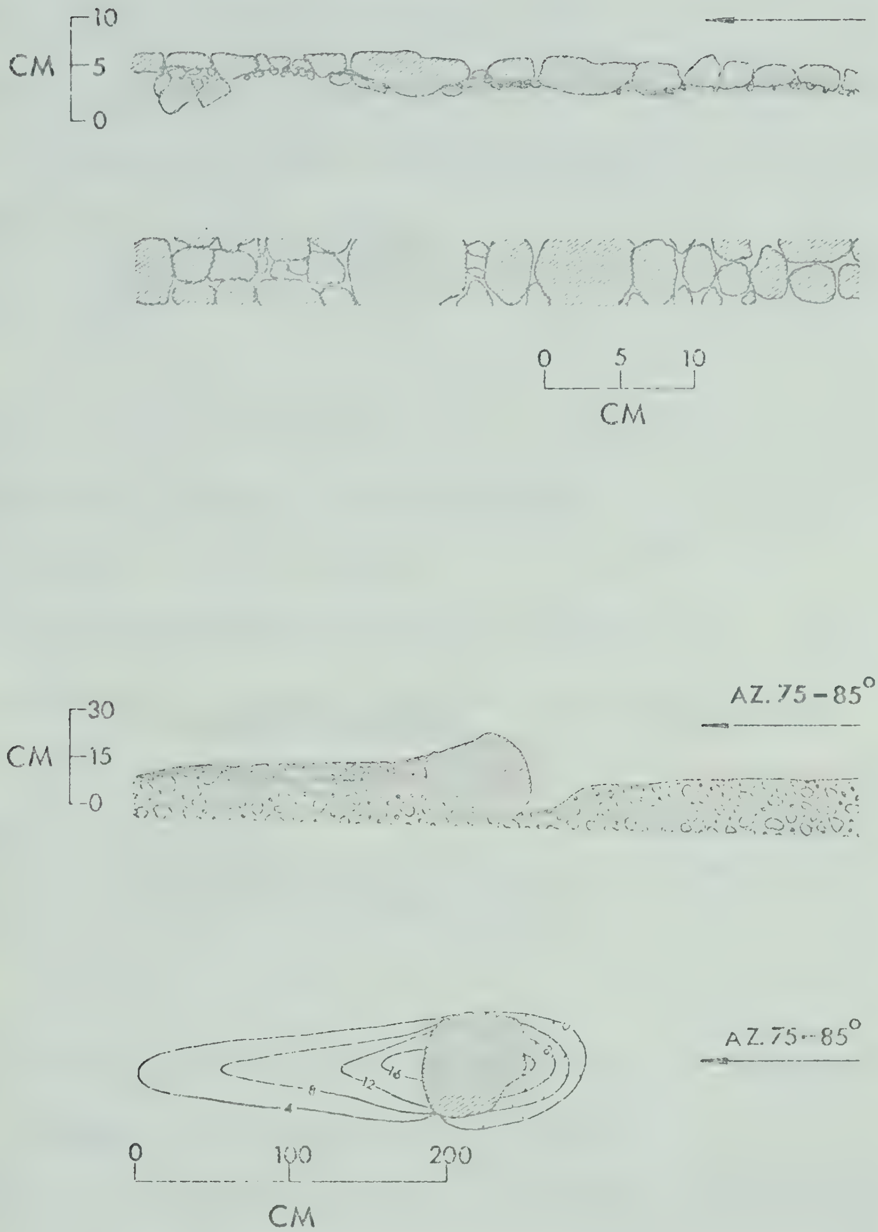


Figure 2.5. Cross-section and plan view of deflation pebble pavement (upper two figures) and cross-section and plan view of pebble dune (lower two figures). Contour interval in centimeters.

coal up to 6 cm long were observed on top of the snow in places where it was not possible for the cobbles to roll to.

Bagnold (1954, p. 101) gives an equation that relates the velocity gradient V_{*t} which must be attained by air before it can move any surface grains over a rough surface.

$$V_{*t} = A \sqrt{\frac{\sigma - p}{p} gd}$$

where

A is a coefficient equal to 0.1

σ = density in gm cm^{-3} of rock particle

p = density of air in gm cm^{-3} = 1.22×10^{-3}

g = acceleration due to gravity in cm sec^{-2}

d = diameter of grains in cm (not less than 0.02 cm)

"From this the threshold velocity V_t in cm sec^{-1} at any height z above the surface is given by"

$$V_t = 5.75\, A \sqrt{\frac{\sigma - p}{p} gd}\, \log \frac{z}{k}$$

where

k = surface roughness (defined as 1/30 of the diameter of surface boulders and other symbols as above)

Figure 2.6 gives the grain size, lithology and bulk density of the particles and the calculated threshold wind velocity required to initiate movement of that particle over the ground surface (roughness (k) = 1 cm). From Figure 2.6 and the range of sizes of particles sampled in the minesite it is possible to estimate the maximum wind speeds at 1.3 m above the ground surface that occur in the minesite. Sample C shows the maximum wind velocity to be 160 kph but this represents air streaming around the boulder in front of the dune to which the large pebbles

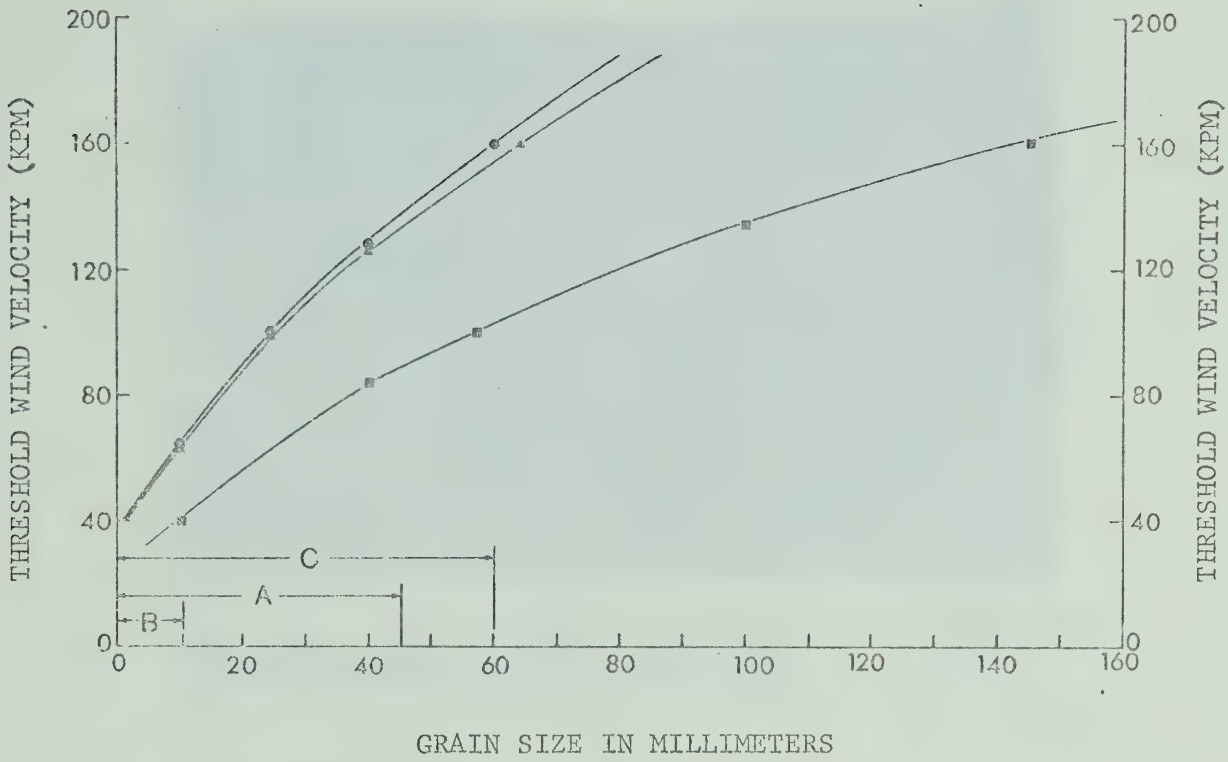


Figure 2.6. Threshold velocity of wind at 1.3 m above ground surface for sandstone (bulk density, 2.32 gm cm^{-3}) (dot), shale (bulk density, 2.20 gm cm^{-3}) (triangle) and coal (density 0.97 gm cm^{-3}) (square) particles, and particle grain size; grain-size range of samples A, B and C collected in the minesite.

were moved and is not representative of open flat areas in the minesite although it does correspond well with reported maximum winds in the area (160 kph; Edmonton Journal, 1973). Sample A is more representative and gives values of 130 kph as maximum. The mean grain size for Sample A (Plate 2.19) and the maximum grain size of Sample B is about 1 cm. This gives average values of wind speed of about 65 kph. (Winds of this velocity were experienced during snow surveys in March 1972 and January 1973).

In view of the size of particles transported in the minesite the

P. 26 located after P. 36

Plate 2.1. View looking east over main pit. Inverted conical subsidence pits in foreground.

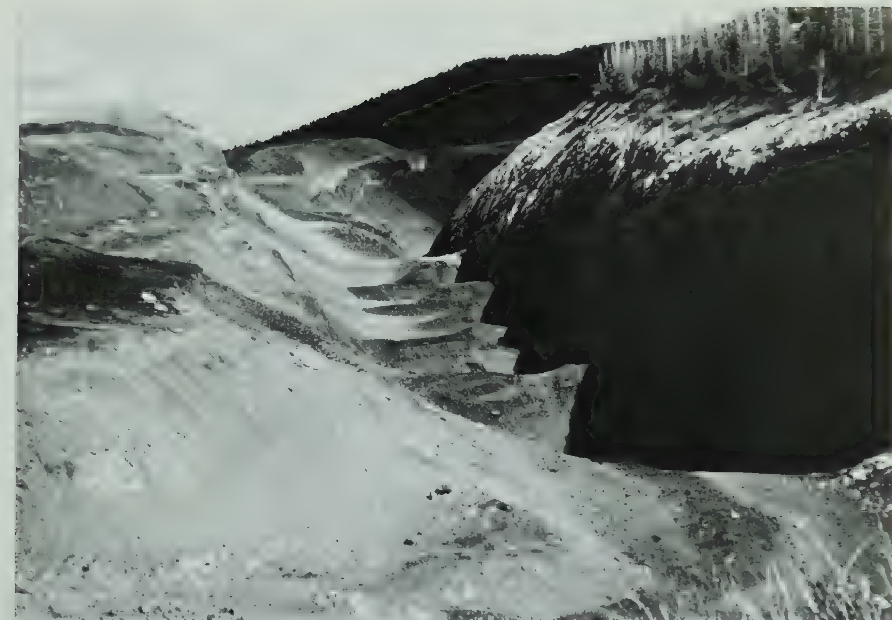


Plate 2.2. View looking north over the spoil piles of the main pit. Immediate foreground shows pebble deflation pavement and Engelmann spruce (<u>Picea engelmannii</u>) that has been damaged by wind-blown particles of snow and rock. Flagged and krumholtz trees are also present in the center right. In the center ground four gullies are present. The treeline of the horizon is maintained by moisture deficiency caused by removal of snowfall by persistent winter winds from the west.

Plate 2.3. Weathering of a block of shale capped with an ironstone bed. The shale breaks down to flaky, angular diamond or rectangular shapes whereas the ironstone weathers to near cubes. Hammer handle is 17.5 cm long.

Plate 2.4. Flaky, angular disintegration of laminated silty sandstone. Hammer is 30 cm long.

Plate 2.5. Blocky disintegration of remnant ironstone bed on top of weakly kaolinite-cemented sandstone.

Plate 2.6. Exfoliation weathering of kaolinite-cemented sandstone and extension of debris downslope.

Plate 2.7. Exfoliation weathering of surface exposure of large boulder of kaolinite-cemented sandstone and extension of debris downslope. Hammer handle points downslope.

Plate 2.8. Exfoliation weathering of kaolinite-cemented sandstone; weathered rind was about 5 cm thick.

Plate 2.9. Angular disintegration of flat sandstone cobble on horizontal surface of spoil. Individual sections have been moved apart by frost-wedging and needle-ice. A pebble deflation pavement surrounds the broken cobble.

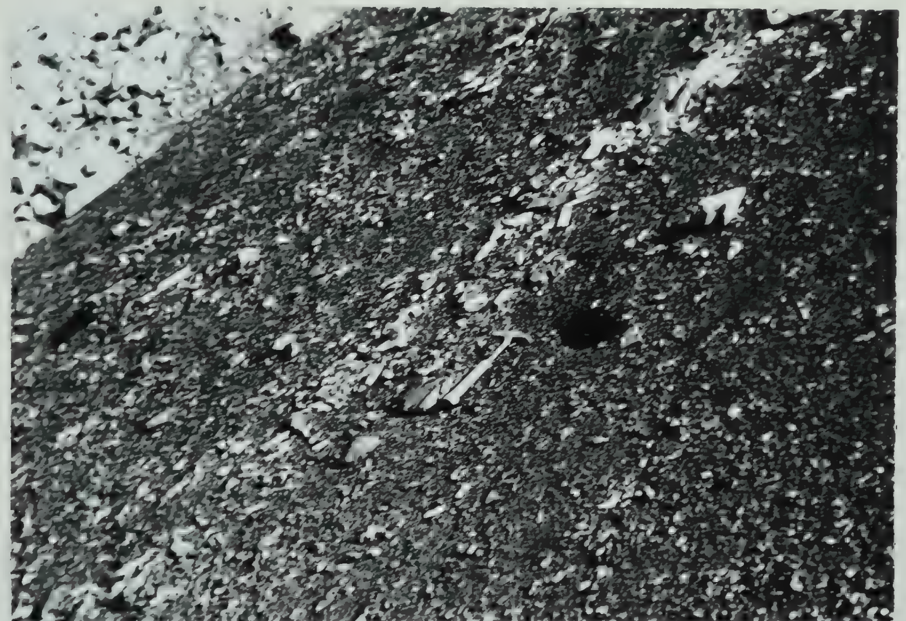


Plate 2.10. Downslope movement of frost-shattered light-toned sandstone.

Plate 2.11. Deflation hollow under a boulder of quartz-cemented sandstone. Wind-shifted material directly behind the boulder has pebbles up to 4 cm in diameter. Note also the surrounding pebble deflation pavement.

Plate 2.12. Wind-blown rock particles deposited on sandstone boulder at east end of minesite.

Plate 2.13. Snowbank on north side of spoil below minesite on June 1, 1972.

Plate 2.14. Snowbank on north side of spoil below minesite on June 1, 1972. Bare spoil is visible in upper left; foreground shows snow with thin mantle of rock particles; lower right shows thick "niv-aeolian" mantle (terminology after Hamelin and Cook, 1967).

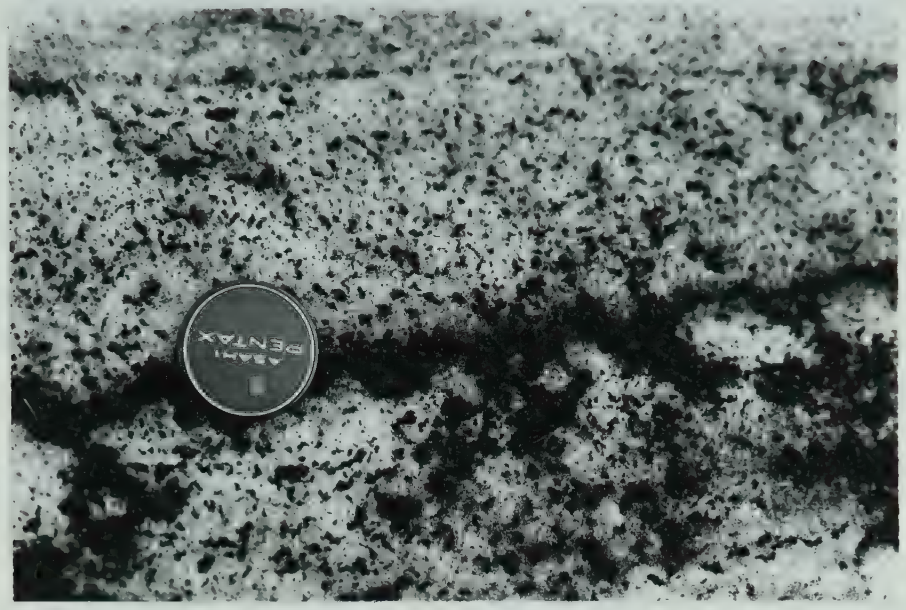


Plate 2.15. Bands of rock particles in snowbank shown in Plate 2.13.

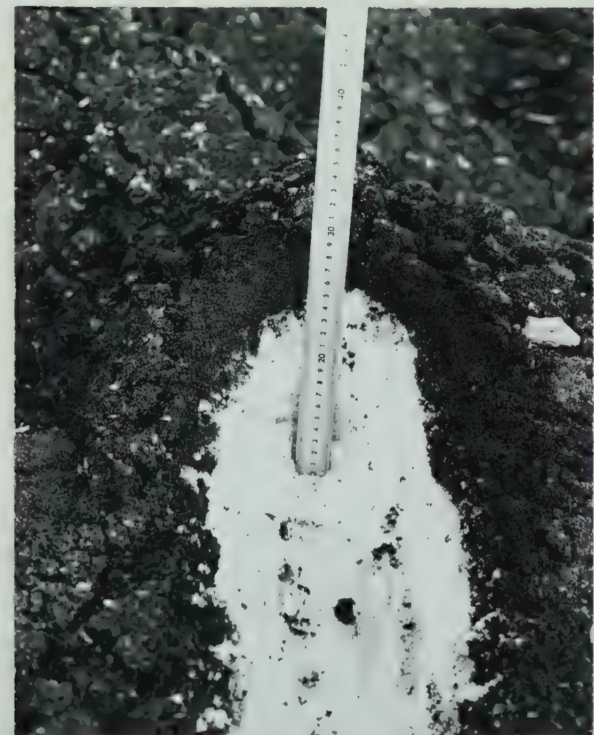


Plate 2.16. Thick (7 - 20 cm) mantle of rock particles over snowbank shown in Plate 2.13. The large pebble at right center is 5 cm long and is sandstone of 2.32 gm cm^{-3} bulk density. It would require a wind velocity of 140 kph to initiate movement.

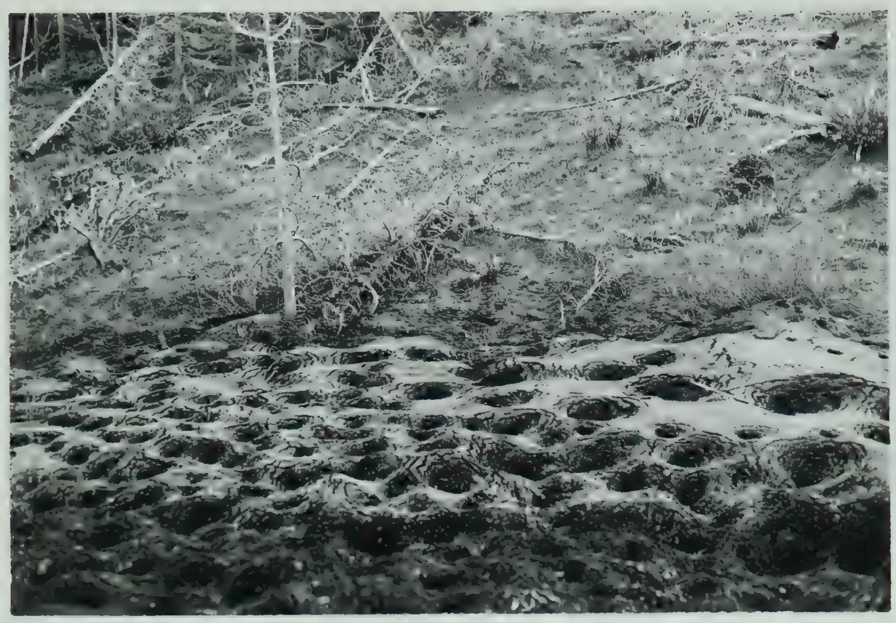


Plate. 2.17. Insulation provided by the thick mantle of rock particles inhibits snowmelt and leads to this interesting kettle-type topography. Snow still underlies the mantle and reflects the surface topography. The white, straight stick is 1 m long. The adjacent lodgepole pine (Pinus contorta var. latifolia) have been killed, blown down and buried beneath the wind-blown rock debris.

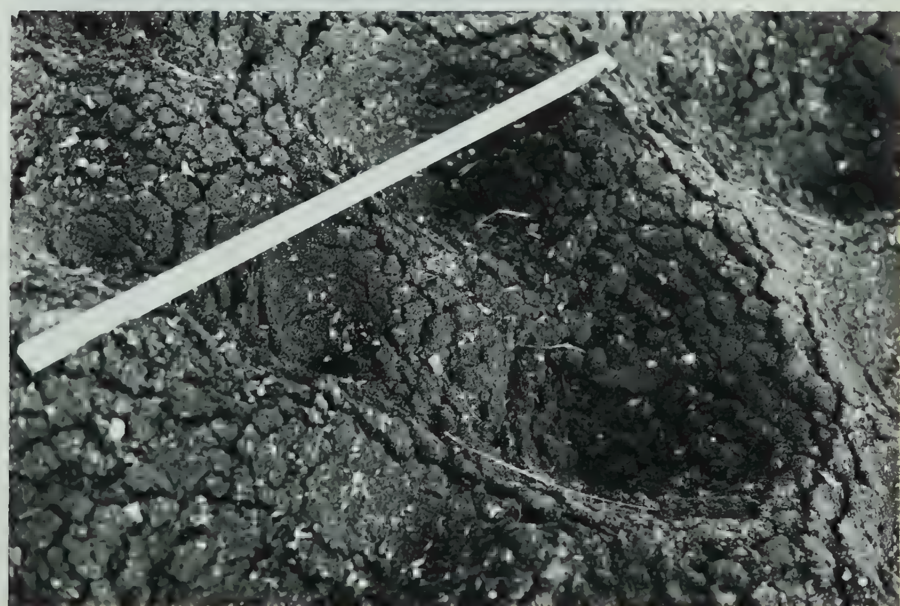


Plate 2.18. "Kettles" in rock particle-covered snowbank shown in Plate 2.13. Scale is 1 m long.

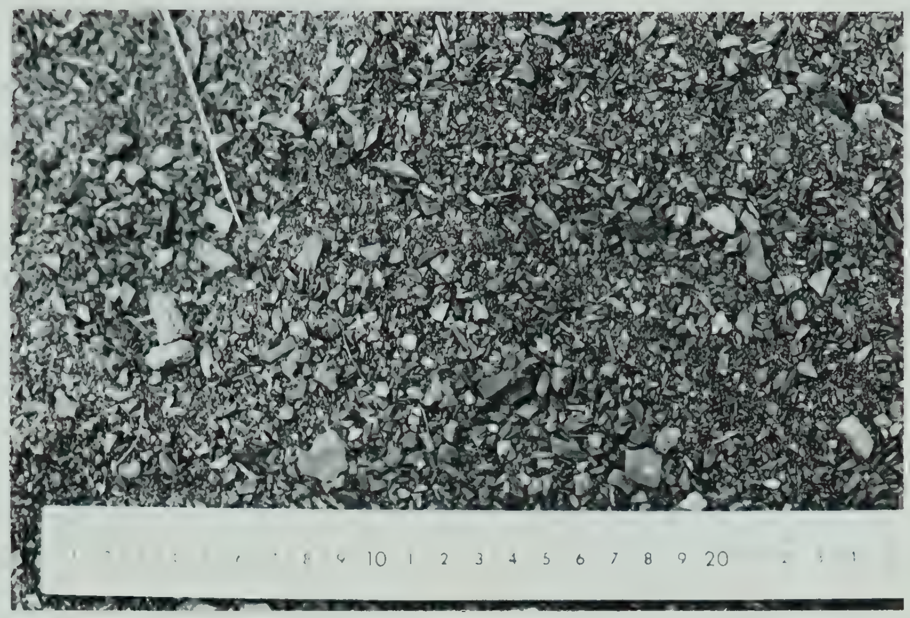


Plate 2.19. Wind-blown rock particles at the base of snowbank-covered spoil on north side of minesite. Pebbles are mainly shale, coal and sandstone.

Plate 2.20. Soil pit excavated at control station 2 on north side of the minesite. The profile shows 6 - 10 cm of wind-blown rock particles over 5 - 10 cm of buried organic horizons (Ah) over 25 cm of disturbed sandy loam with few large pebbles and cobbles (Bm) over weathered sandstone bedrock (C).

values obtained using Bagnold's equation give reasonable results and indicate the occurrence of extremely high winds in the minesite during the winter. The pebble deflation pavement characteristic of the minesite and the pebble dunes in the lee of boulders are thus reasonable results of the winter wind in the minesite. The effects of these winds on moisture supply and vegetation will be discussed in chapters IV and V.

<u>Summary</u>

(1) The Luscar Formation, from which the coal mined at Cadomin came, extends from Nordegg in the central Alberta Foothills to northeastern British Columbia and as the formation has similar lithologic character throughout its length the conditions at the Cadomin minesite are typical of geologic conditions that would arise from the extraction of coal from this formation.

(2) The spoil materials are composed of various proportions of coarse, angular sandstone, shale, siltstone, coal and conglomerate.

(3) The spoil materials at the surface weather extremely rapidly by physical processes.

(4) Little evidence of chemical weathering was noted.

(5) Slopes of spoil piles are stable and are reduced only by the downslope movement of fine-grained rock waste.

(6) Talus creep and frost creep are the dominant mass-wasting processes.

(7) Erosion by running water is minor.

(8) Erosion and deposition by wind is significant and results in a deflation pavement of angular, coarse material at the surface of the minesite. The coarse grain size of samples of wind-blown material taken in the minesite indicate extremely high winds occur in the minesite during winter.

CHAPTER III

SURFACE DRAINAGE AND GROUNDWATER

The storage, movement and chemical quality of surface and subsurface water within the study area will be discussed.

Surface water

Figure 3.1 shows the lakes, drainage and groundwater flow direction and gives the locations of water samples taken in the study area.

Two creeks flow into the study area from the mountainside on the south side. Both creeks were diverted during the mining operations to circumvent the minesite by ditching (east creek) and artificial channelling (west creek). The ditching has remained relatively stable and the east creek is still contained by the ditch. The artificial channelling has collapsed and the west creek flows into the minesite through spoil material and over the highwall into the lake in the main pit. Snowpack is the principal source of water for the creeks and flow in both creeks is minor (3 liters /sec) after the disappearance of the snowpack. As a result of the low flow little erosion by the creeks has occurred since the minesite was abandoned.

Surface water is ponded in two pits within the minesite. The upper lake is shallow and has a surface area of approximately 5.12×10^2 sq. m. The lower lake is ponded in the main pit, is of unknown depth and has a surface area of approximately 8.46×10^3 sq. m. The lakes are maintained by direct precipitation and groundwater discharge.

The main lake supplies water to a large spring (discharge at end of summer of 1972 approximately 50 liters/sec) below the minesite (Figure 3.1, spring No. 5) and to numerous adjacent smaller springs discharging

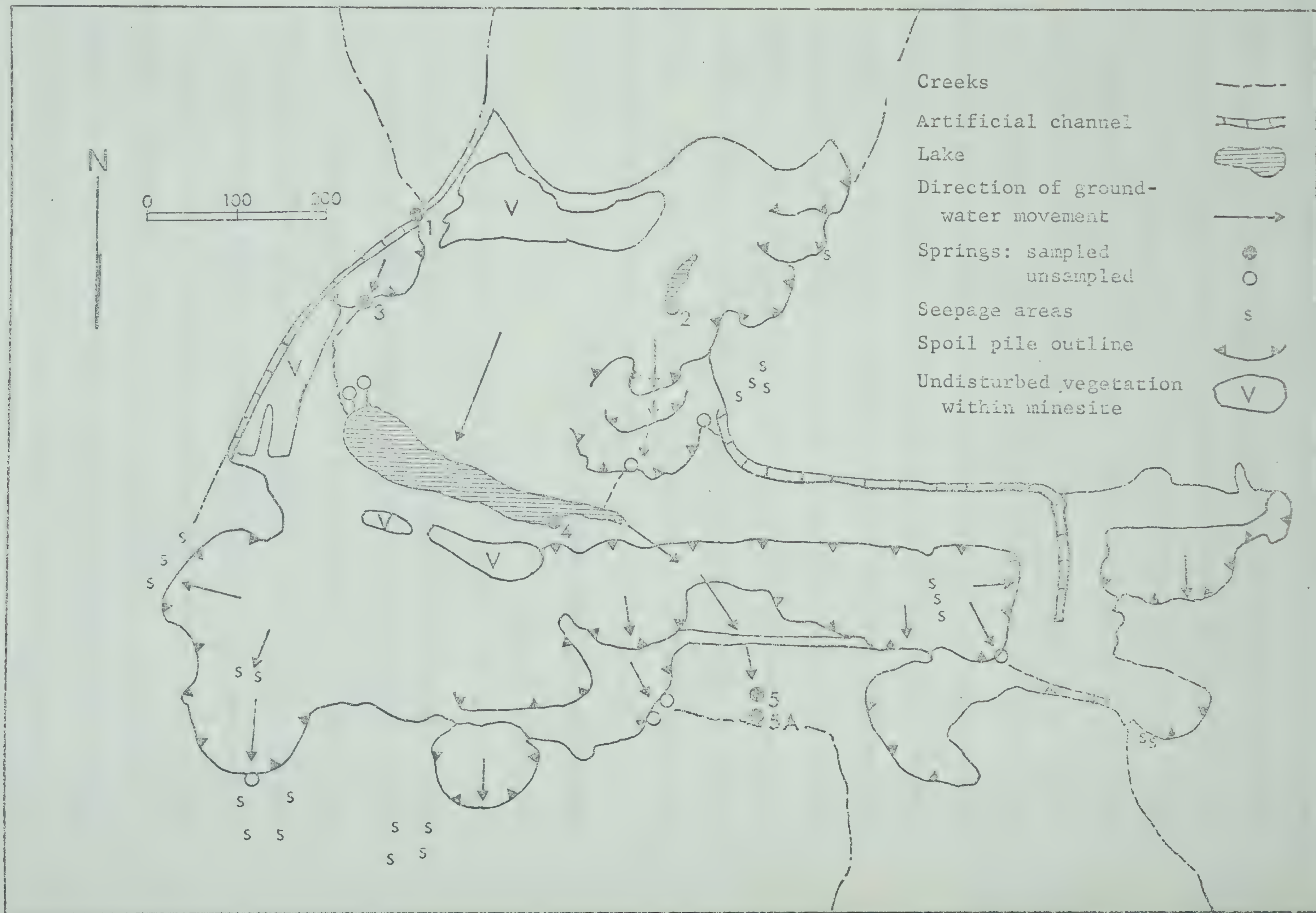


Figure 3.1. Surface water, drainage, groundwater movement and discharge, and locations of samples taken for chemical analysis.

at the base of the spoil. The upper lake is drained by subsurface flow through spoil material and, at high stage only, by an outlet channel.

Runoff from the spoil itself and from land disturbed by mining is rare and was observed only briefly after a light snowfall, followed by freezing and rapid surface melt. Rainfall on June 24th and 25th amounted to 5.3 cm but no runoff was observed although the spoil had been moistened by a rainfall of 3.8 cm on June 21st and 22nd. The minesite has developed few gullies or incised drainage channels since it was abandoned in 1952 (Figure 2.3) and, as long gentle slopes and short steep slopes are abundant and the spoil is easily eroded, overland runoff must be rare.

Infiltration and soil temperature profiles

The term infiltration is used here to describe the process whereby water soaks into, or is absorbed by, the soil (Horton, 1933). As runoff is rare in the minesite the infiltration capacity of the spoil (i.e., the maximum rate at which water can be absorbed by a soil in a given condition) is seldom exceeded. The infiltration capacity of a soil determines not only how much water enters into the soil to be moved downward by percolation into groundwater but also the amount of soil moisture moved upward to the atmosphere by evaporation and transpiration (Ward, 1967). The spoil is angular, coarse material with many large interstices so that the infiltration capacity is high and water will infiltrate rapidly. Water, water vapour, and air are the principal media by which heat is transported into or out of the soil and hence soil temperature profiles measured prior to and after a cold rainfall provide an indication of the rate of infiltration. Figure 3.2 shows the air temperature, rainfall amount and duration, and soil temperatures

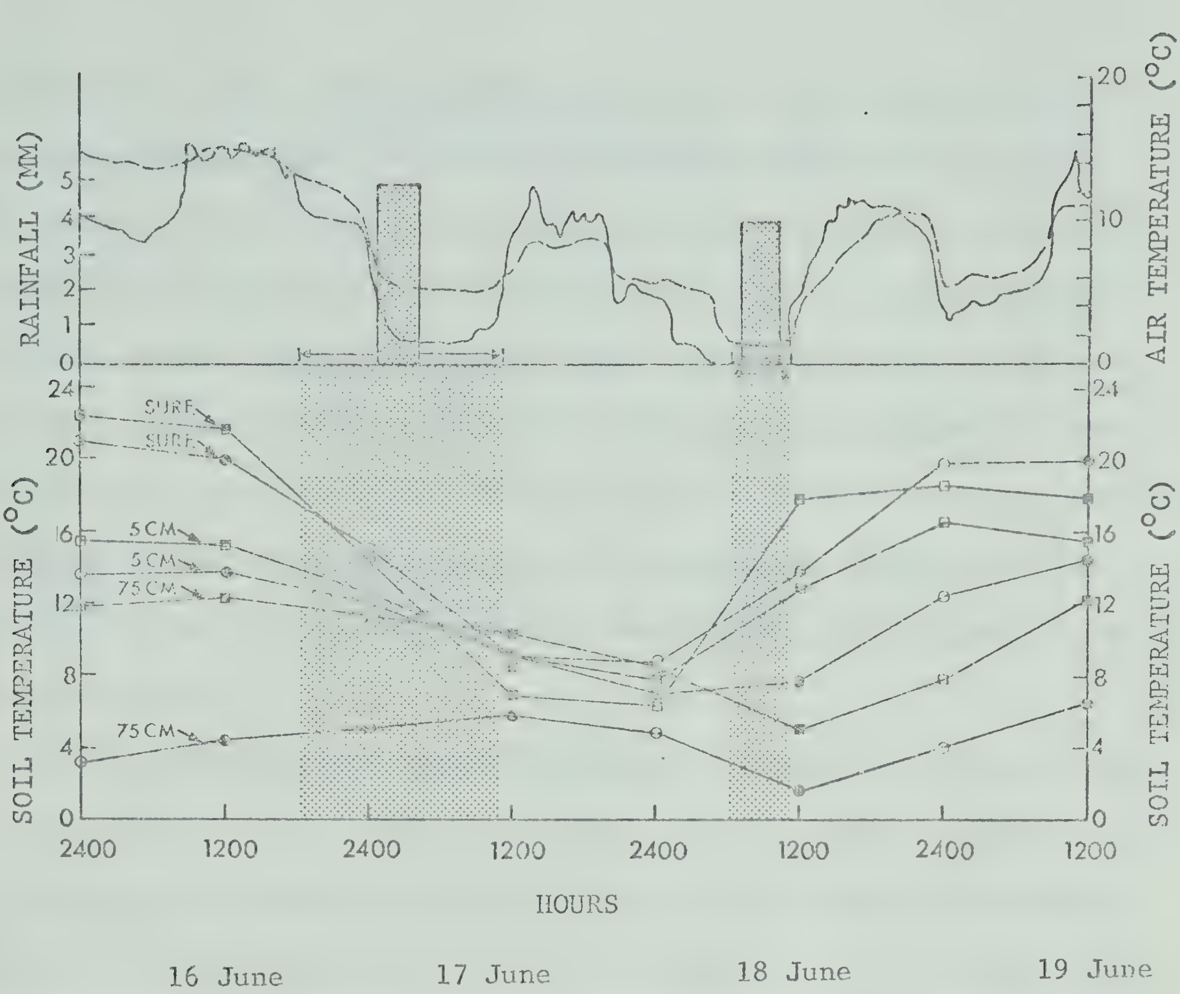


Figure 3.2. Rainfall amount and duration (shaded area); air temperature at control station 1 (full line) and minesite station 3 (dashed line); soil temperatures at the surface, 5 cm and 75 cm depth for control station 1 (full line and dot) and minesite station 3 (full line and square). Open dots and squares are estimated values.

at the surface, 5 cm, and 75 cm depth for control station 1 and minesite station 3 for 0000 hours on June 16th to 2400 hours on June 19th. The soil temperature profile at the control station shows a 16°C difference between the surface temperature and the temperature at 75 cm prior to the June 16th rainfall; in contrast, the minesite station shows a temperature difference of 9°C between the surface and 75 cm. Between

1200 hours on June 16th and 1200 hours on June 17th soil temperatures were depressed due to the infiltration of cold water from rainfall. The surface and 5 cm soil temperatures for both stations show similar temperature depressions but the temperature at 75 cm at the minesite station shows a depression of 2°C, whereas the temperature at 75 cm at control station 1 shows an increase of 2°C for the same period. Thus, as the soil is cooled by the infiltration of cold water and as the soil temperature at control station 1 at 75 cm actually increased the rate of percolation must be more rapid at the minesite station than at the control station.

After the June 18th rainfall surface soil temperatures increased at both stations. At 1200 hours on June 19th the surface temperature at the minesite station was lower at the control station and probably resulted from greater evaporation at the surface. The 5 cm soil temperatures show that the top 5 centimeters of the soil in the minesite warmed more rapidly than the top 5 centimeters of the soil in the control area. Considerably more heat is required to warm water-saturated soil than dry soil so that the more rapid increase of soil temperature at the 5 cm depth in the minesite indicates that more moisture had moved away from the surface layer of the soil in the minesite than in the control area. The soil temperature for the minesite station at 75 cm after 1200 hours on June 18th warmed more slowly than the 5 cm soil temperature and probably indicates the influx of cold water from the upper layers of soil. Thus water is lost more rapidly by evaporation and percolation from the surface layers of soil in the minesite than in the control area.

Soil temperature measurements made throughout June to August indicate that the soil temperature gradient is much less pronounced in the mine-

site than in the control area, that soil temperatures are generally higher in the minesite and that the spoil materials in the minesite respond much more rapidly to the influx of heat or cold than the control area (Figure 3.3). In the control area the thin mantle of organic-rich soil that covers the weathered bedrock retards the infiltration of water and thus retards the inflow of heat and cold; however the water is retained close to the surface once it has infiltrated and the organic-rich soil inhibits moisture loss by evaporation. In the minesite infiltration of water and thus the inflow of heat and cold is rapid, percolation is rapid and there is no organic-rich soil to retard evaporation. The rapid fluctuations in spoil temperatures compared to the control area, the lack of runoff and the coarse, angular spoil material indicate that the spoil materials are highly permeable and allow the rapid inflow and outflow of water, water vapour and air. Consequently the spoil materials have little capacity to retain moisture close to the soil surface.

Groundwater

Spring discharge

Numerous springs and seeps occur in the study area. The large spring below the minesite discharges year round and feeds the creek leading away from the study area (Figure 3.1). The smaller springs are dependant on the flow of water from the east and west creeks and from direct precipitation.

Chemical analysis of water samples

To determine the changes that occur when water passes through spoil material, samples of water were taken from the east creek above the minesite and from the upper lake. These samples were considered to

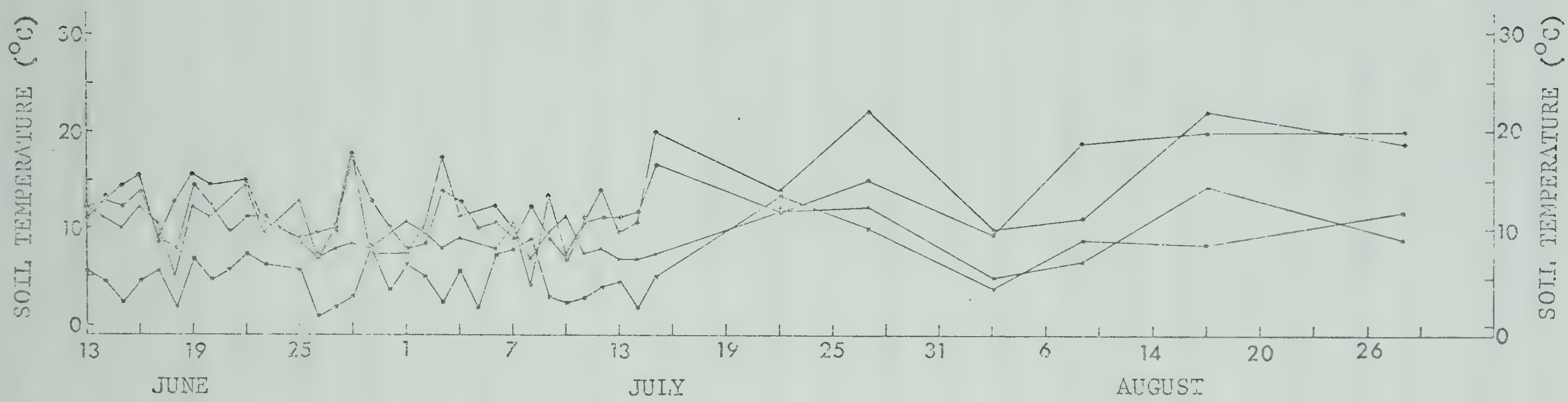


Figure 3.3. Soil temperatures at 5 cm and 75 cm for control station 1 (dot and square respectively) and minesite station 3 (diamond and triangle respectively).

be control samples representative of runoff in the undisturbed area surrounding the minesite. Samples were taken from the main lake, from a small spring issuing from the base of a small spoil adjacent to the east creek, and from a large spring which drains the main lake via bedrock and an abandoned mine shaft. These samples were considered representative of water that had passed through spoil materials. The samples were taken in June after snowmelt and the major runoff.

An analysis of the samples shows that there is little difference in chemical and physical properties of the samples. Total dissolved solids, total calcium carbonate hardness, total calcium carbonate alkalinity, pH and chemical constituents of the water change little after passing through spoil material. All the samples were pure enough to conform to drinking water standards used in Alberta. Table 3.1 gives the analysis of each water sample. The data are shown in Figure 3.4 plotted as Stiff diagrams and in Figure 3.5 as a Piper's diagram.

The Stiff diagrams show that as water flows through spoil it picks up sodium, potassium and bicarbonate ions. No noticable increase in iron, chloride or carbonate ions is apparent. A slight increase in the sulphate ion and a slight increase in the magnesium ion is indicated.

Piper's diagram indicates that for all water samples collected alkaline earths exceed alkalies, weak acids exceed strong acids and carbonate hardness exceeds 50 percent so that the chemical properties of the groundwater are dominated by alkaline earths and weak acids.

Unfortunately there are no comparable data measured for other minesites in the Alberta Foothills (R. Green, pers. comm., 1972) so that it is not possible to determine whether the analyses shown are representative of groundwater quality conditions that would arise immediately

Table 3.1. Chemical analysis of water sampled above, within and below the minesite

	Parts per million	Upper lake	Upper east creek	Upper east spring	Main lake	Large spring below minesite	Large spring below minesite	Alberta potable water supply chemical limits ppm
		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 5A	
General	Total dissolved solids	254	168	174	196	298	292	1000
	Total hardness as $CaCO_3$	263	166	172	159	173	175	100
	Total alkalinity ($CaCO_3$)	184	158	170	194	294	278	400
	pH	8.2	8.1	8.2	8.1	8.2	7.9	4.5 - 10
Major constituents	Calcium (Ca^{++})	64.0	43.0	51.0	41.3	44.2	45.0	200
	Magnesium (Mg^{++})	25.0	14.2	10.7	13.4	15.2	15.2	150
	Sodium (Na^{+})	2.5	3.8	5.0	33.0	65.0	44.0	300
	Potassium (K^{+})	0.4	0.0	0.0	0.8	0.8	0.8	300
	Carbonate (CO_3^{--})	0.0	0.0	0.0	0.0	0.0	0.0	400
	Bicarbonate (HCO_3^{-})	184.0	158.0	170.0	194.0	294.0	278.0	400
	Sulphate (SO_4^{--})	71.0	14.0	7.0	15.0	20.0	17.7	250
	Chloride (Cl^{-})	1.0	3.0	1.0	1.0	1.0	0.0	250
	Nitrate (NO_3^{--})	0.6	0.5	0.6	0.6	0.7	0.4	10
Minor constituents	Iron (Fe) in solution	0.05	0.07	0.05	0.08	0.07	0.07	-
	Fluorine (F)	0.15	0.24	0.11	0.20	0.32	0.32	1.5

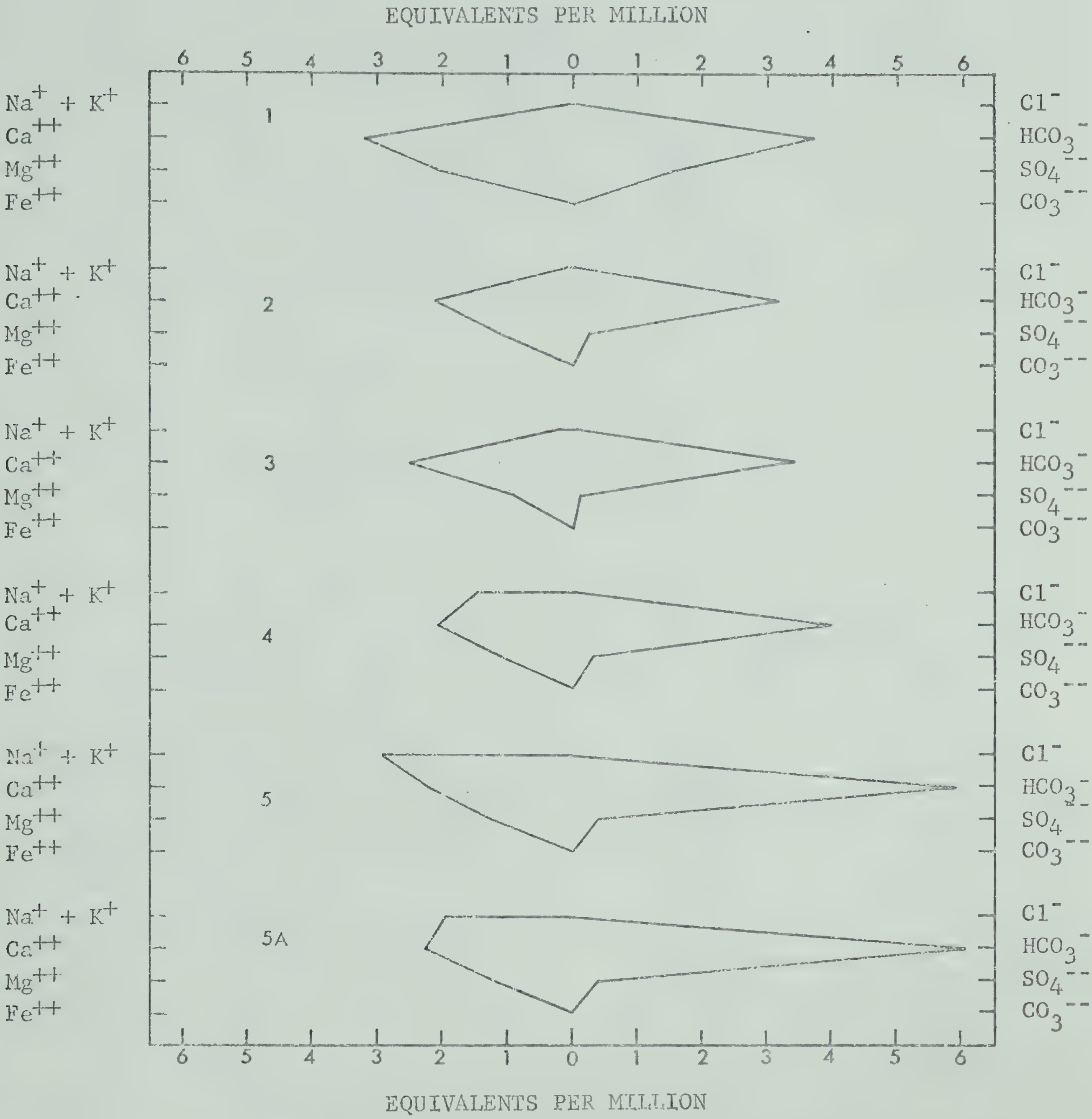
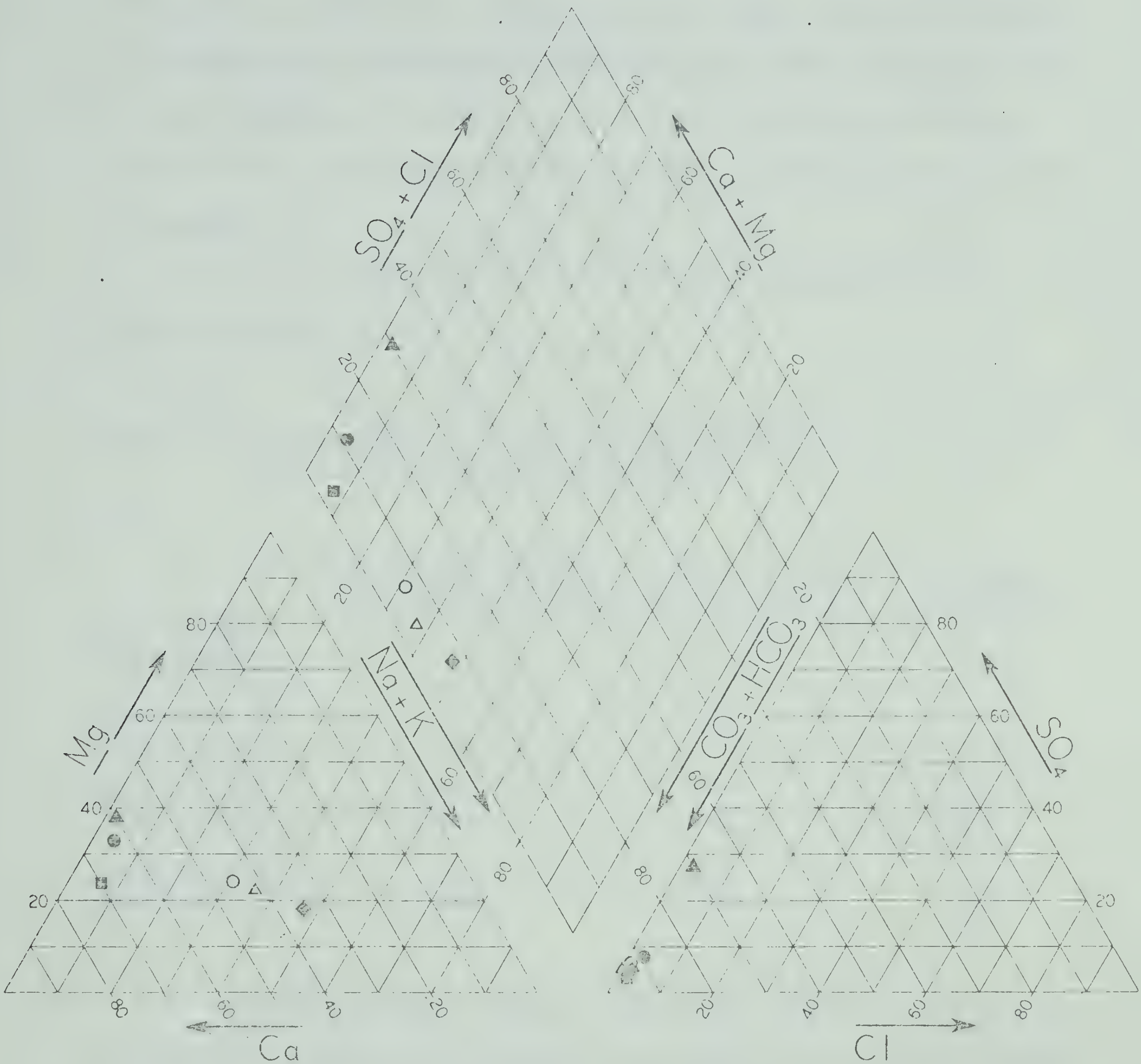


Figure 3.4. Stiff diagrams of water sampled above, within and below the minesite. Note: equivalents per million (epm) is calculated by dividing parts per million (ppm) by the equivalent weight of the ion under consideration (Walton, 1970, p. 440). (Sample 1, upper lake; Sample 2, upper east creek; Sample 3, upper east spring; Sample 4, main lake; Sample 5, large spring below minesite; Sample 5A, large spring below minesite).



PERCENT OF TOTAL EQUIVALENTS PER MILLION

▲	Upper lake	Sample 1
●	Upper east creek	Sample 2
■	Upper east spring	Sample 3
○	Main lake	Sample 4
◆△	Large spring below minesite	Samples 5 and 5A

Figure 3.5. Piper's diagram of chemical constituents of water samples taken above, within and below the minesite.

after mining or whether the results represent higher quality water after the flushing out of reactive minerals over the 20 year period since the mine was abandoned. Therefore the data are presented here as being representative of groundwater conditions after a relatively short period (20 years).

Table 3.2 gives the horizontal and vertical distance that water flows through the spoil.

Table 3.2. Sample location, horizontal and vertical distances that water flows through spoil material

	Horizontal distance through spoil (m)	Vertical distance through spoil (m)	Distance (Resultant)
East spring to upper spring	96	12	97
East creek to main lake	220	71	231
Main lake to lower spring	274	25	277
Upper lake to main lake	274	95	288

It is well established that the longer water stays in contact with rock material underground the greater the changes that will occur in its chemical quality. Chebotarev (1955, p. 210) states that "The duration of time of the contact of water with the geological formation in the subsurface reservoirs and the continuity of the movement of water are important factors influencing the chemical change of subterranean waters". The lack of substantial chemical changes indicates that the water is not in contact with the spoil materials for very long. It has

been shown that the infiltration into the spoil is rapid; the chemical data suggest that groundwater flow is rapid and that the spoil material is highly permeable and only slightly reactive with the water moving through it. These conclusions are supported by the observed abrupt commencement and termination of the smaller spring discharges after precipitation, the absence of runoff, the coarse texture of the spoil, the rapid fluctuation and uniform gradient of spoil temperatures and the absence of widespread slump and flow landforms. The spoil transmits water rapidly and little is retained in the spoil itself.

Summary

Spoil materials are highly permeable and allow the rapid inflow and outflow of water, water vapour and air and consequently the rapid inflow and outflow of heat. Water infiltrates and moves through the spoil material rapidly and little is stored within the spoil itself. Spoil materials have little capacity to retain moisture close to the soil surface. The chemical and physical quality of water passing through the spoil material is not significantly changed.

CHAPTER IV

CLIMATE AND MICROCLIMATE

The instrumentation of the study area and the climatic records made at the study area will be discussed and the records taken compared with other permanent climatic stations. The microclimate of the minesite will then be compared with the microclimate of the control area.

Terminology

Microclimatic stations within the control area are called control station 1 and control station 2, and are abbreviated to C1 and C2 in the tables. Microclimatic stations within the minesite are called minesite stations 2, 3, and 5 and are abbreviated to S2, S3, and S5 in the tables. All figures quoted will be in the metric system, for example, degrees centigrade (°C) and millimeters (mm) of rainfall or snowfall.

Instrumentation

Figure 4.1 shows the instrumentation installed in the study area and Table 4.1 gives the record and site conditions of the microclimatic stations.

Installation, calibration and reliability of instruments

Stevenson screens were installed at all stations at the standard height of 1.3 m facing north. Lambrecht recording hygrothermographs were calibrated against a precise mercury thermometer (Fisher), a Thermo Electric Minimite II potentiometer and copper-constantan thermocouple, a maximum and minimum thermometer and a sling psychrometer and were installed in the Stevenson screens. The hygrothermographs were allowed one week of operation during which they were recalibrated twice daily. Precipitation guages were installed at each station.

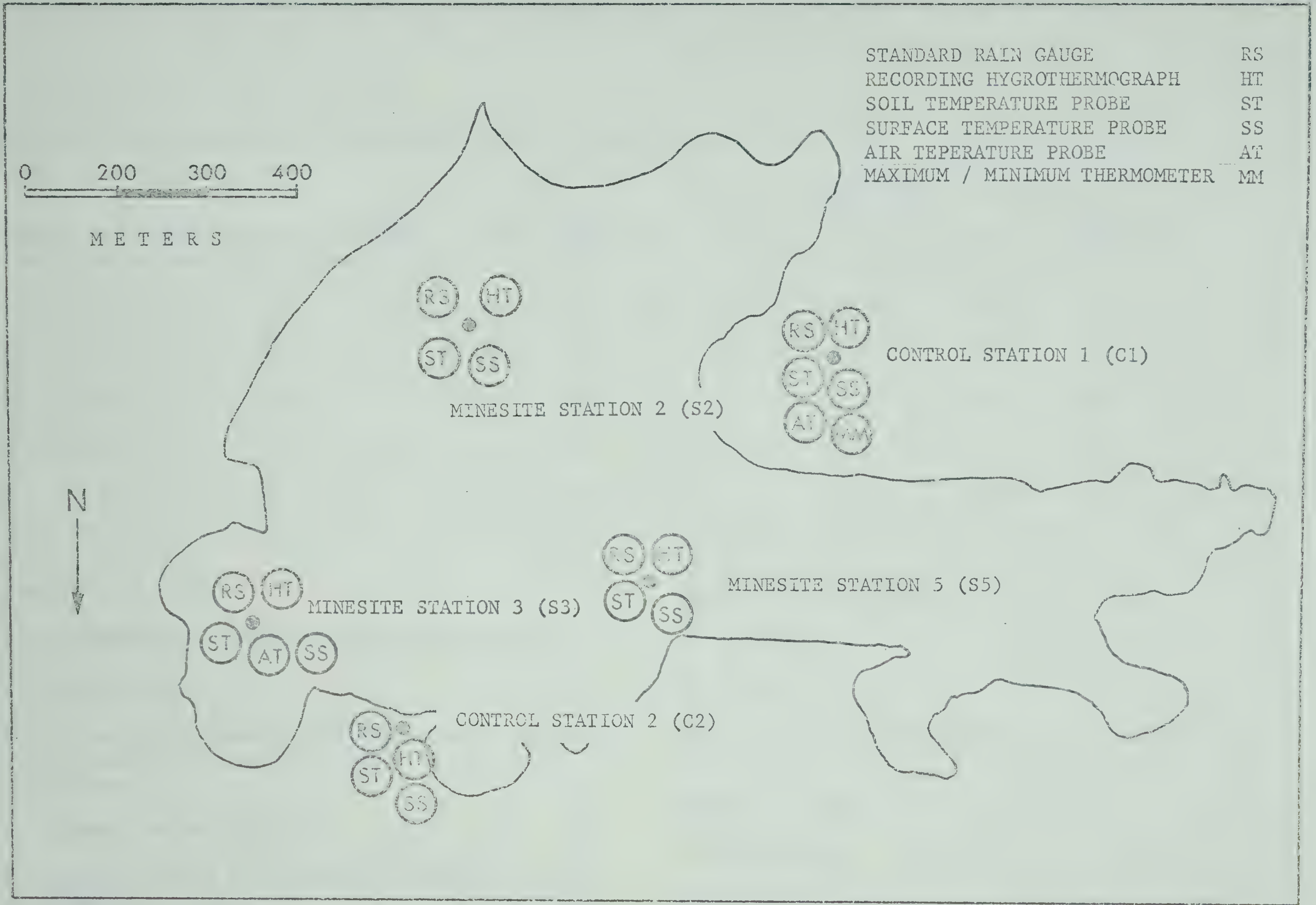


Figure 4.1. Microclimatic stations in the study area.

Table 4.1. Instrumentation of the microclimatic stations in the study area

Station	Air temp.	R.H.	Precip.	Air temp. profile	Surface temp.	Soil temp.	Wind	Max. min. temp.	Accuracy of record overall	Elevation above msl	Elevation above C1
C1	C_E	C_G	P_E	P_E	P_E	P_E	P_E	C_E	E	1705	0
C2	C_E	C_G	P_E	-	P_E	P_E	O	-	E	1673	-32
S2	C_E	C_G	P_G	-	P_E	P_E	O	-	G	1738	+33
S3	C_E	C_G	P_E	P_E	P_E	P_E	P_E	-	E	1704	-1
S5	C_E	C_G	P_E	-	P_E	P_E	O	-	E	1696	-9

Remarks

C1 In vegetation, subject to cold air drainage

C2 In vegetation

S2 Precipitation measurements discontinued because of animal disturbance. Subject to cold air drainage.

S3 Exposed, on bare ground

S5 Subject to cold air drainage. Exposed on bare ground.

Reliability of record

E - Excellent

G - Good

Poor records were discarded

Nature of record

C - Continuous

P - Periodic

O - Occasional

Soil temperature probes were installed at all stations to measure temperatures at 5, 20, 50 and 75 cm below the soil surface via copper-constantan thermocouples and a Minimite II potentiometer. The soil temperature probes were allowed one week to become adjusted before records were considered reliable. Thermocouples were installed to measure air temperatures at 5, 20, 50 and 100 cm above the soil surface at control station 1 and minesite station 3. Each of the thermocouples installed had been checked against a mercury thermometer in an ice-bath and at air temperature and were considered reliable.

The instruments were checked against a mercury thermometer and a sling psychrometer during each visit to the microclimatic stations and with the exception of the hair hygrograph little recalibration was necessary. The records kept are considered to be accurate within ± 1°C and within ± 10% relative humidity.

<u>Comparison of temperature and precipitation data with permanent climatological stations operated by the Alberta Forestry Service</u>

Figure 4.2 shows the permanent recording climatological stations closest to the study area.

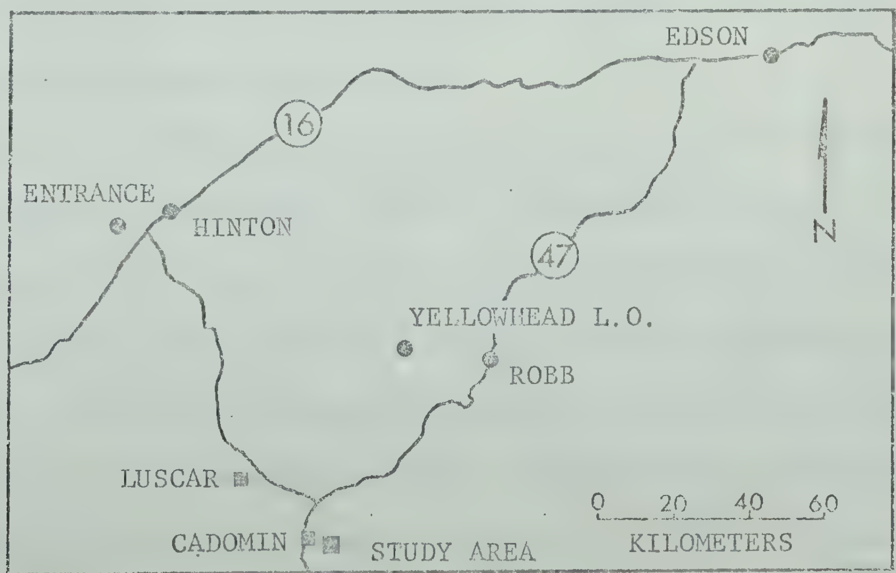


Figure 4.2. Permanent recording weather stations (dots) closest to the study area.

Table 4.2 gives the mean monthly, mean monthly maximum and mean monthly minimum temperatures for each of these stations and for control station 1 and minesite station 3 in the study area for the summer of 1972. The study area is at a higher elevation than the permanent weather stations which accounts for the lower temperatures recorded at the study area. Each mean monthly temperature of the permanent weather stations may be adjusted approximately for elevation difference by

$$T_E = T_R - A\ (E_S - E_R)$$

where T_E = permanent weather station equivalent monthly temperature at elevation of study area in ^{o}C

T_R = permanent weather station monthly temperature in ^{o}C

E_S = elevation of study area in meters

E_R = elevation of permanent weather station in meters

A = average lapse rate of air $6.0^{o}C/10^{3}$ meters

Table 4.2 shows the adjusted temperatures in parentheses and the adjusted mean monthly temperatures are shown in Figure 4.3.

The adjusted mean maximum monthly temperature provides the most useful data for comparison of permanent weather stations with the study area and Table 4.2 shows that the values recorded at the study area are similar to the weather station values.

Table 4.3 and Figure 4.3 show the precipitation for the permanent weather stations and control station 1 and minesite station 3 for June to September 1972. Generally the study area received more rainfall in June and July and less rainfall in August than the permanent weather stations. Table 4.4 and Figure 4.3 show that the average precipitation for Entrance (7 years), Robb (5 years) and Yellowhead Lookout (8 years) and control station 1 and minesite station 3 for June to August 1972.

Table 4.2. Mean, mean minimum and mean maximum monthly temperature of permanent recording weather stations and control station 1 and minesite station 3 and adjusted mean, mean minimum and mean monthly temperatures for permanent weather stations.

AIR TEMPERATURE (°C)

Station	June 72			July 72			Aug. 72			Sept. 72		
	Mn	M	Mx	Mn	M	Mx	Mn	M	Mx	Mn	M	Mx
Entrance (1006 m)	3.8	11.2	18.5	5.6	12.6	19.5	5.8	15.4	24.9	-1.8	4.1	10.0
T_E	(-0.4)	(7.0)	(14.3)	(1.4)	(8.4)	(15.3)	(1.6)	(11.2)	(20.7)	(-6.0)	(-0.1)	(5.8)
Ro (1128 m)	4.0	11.8	17.5	4.7	11.7	18.7	6.8	14.7	22.7	-1.5	3.9	9.2
T_E	(0.5)	(7.3)	(14.0)	(1.2)	(8.2)	(15.2)	(3.3)	(11.2)	(19.2)	(-5.0)	(0.4)	(5.7)
Yellowhead L.O. (1372 m)	5.0	9.9	14.7	5.9	11.1	16.3	8.2	14.2	20.2	1.0*	6.8*	12.6*
T_E	(3.0)	(7.9)	(12.7)	(3.9)	(9.1)	(14.3)	(6.2)	(12.2)	(18.2)	(-1.0)	(4.8)	(10.6)
C_1 (1705 m)	2.8	7.2	11.6	4.4	9.5	14.5	7.4	13.4	19.5	-4.4	-0.6	3.2
S_3 (1704 m)	4.8	7.5	10.2	6.3	10.4	14.5	9.5	14.4	19.4	-3.1	0.4	3.8

* Period from September 1 to 19.

Table 4.3. Precipitation for permanent weather stations. Precipitation for control station 1 and minesite station 3 for June to September 1972 (mm).

Station	June 72	July 72	Aug. 72	Sept. 72	Total
Entrance	104.5	76.8	77.5	102.0	
Robb	109.2	50.0	51.8	125.6	
Yellowhead	91.8	90.2	34.8	64.3*	
C1	117.1	83.1	41.4	-	
S3	116.8	77.5	38.9	-	

* Period between September 1 to 19.

Table 4.4. Long-term average precipitation for Entrance, Robb and Yellowhead Lookout and long-term average temperature for Entrance. Precipitation at control station 1 and minesite station 3.

	Precipitation (in mm)				
Station	June	July	August	Sept.	Period of record in years
Entrance	48.3	76.2	63.5	43.2	7
Robb	81.3	91.4	109.1	45.8	5
Yellowhead Lookout	86.4	91.4	104.1	68.6	8
C1	117.1	83.1	41.4	-	-
S3	116.8	77.5	38.9	-	-
	Temperature (in ^{o}C)				
Entrance	12.0	14.8	13.3	9.6	1931 - 1960
	(7.8)	(10.6)	(9.1)	(5.4)	

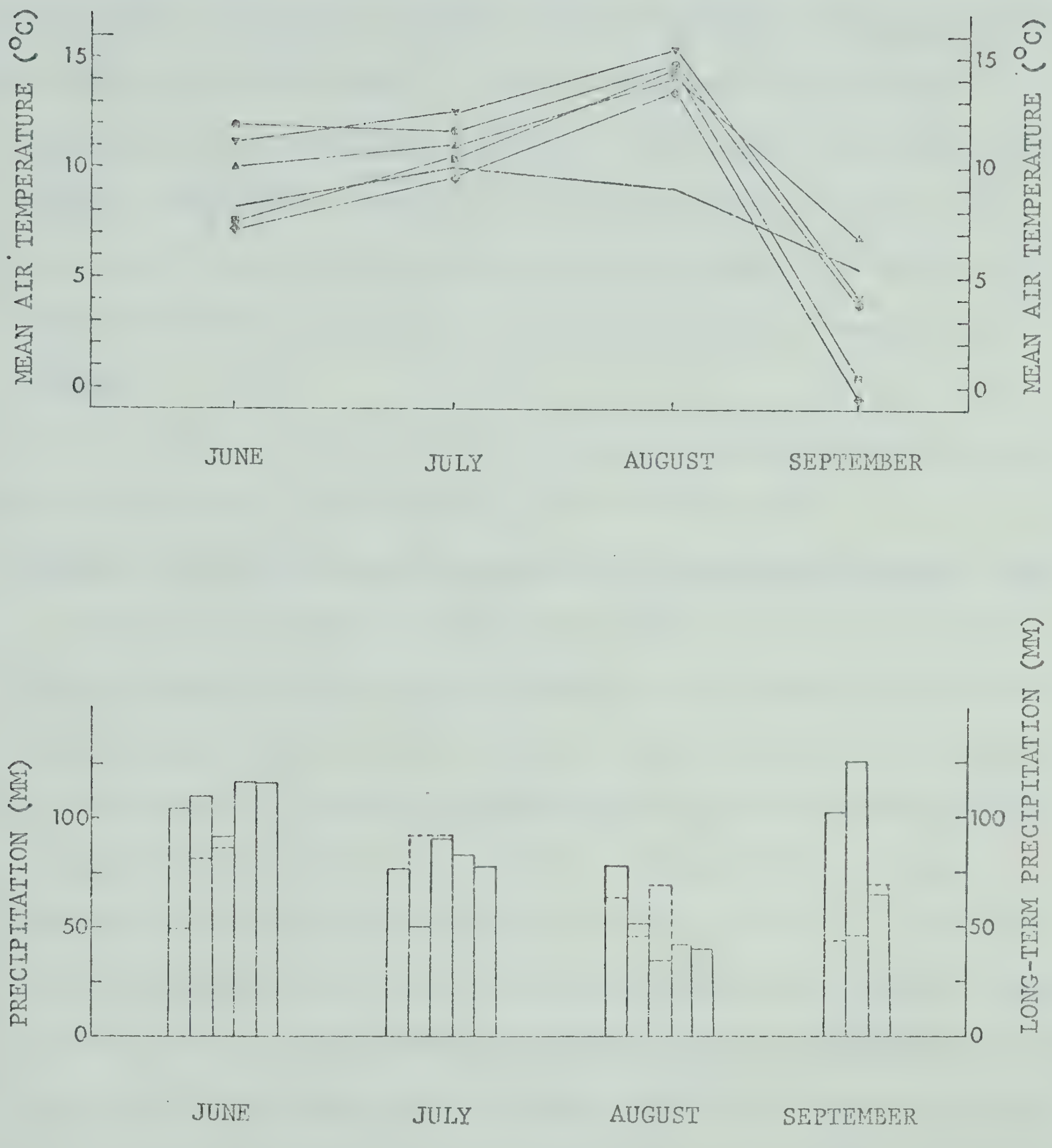


Figure 4.3. Mean monthly temperature (upper diagram) for control station 1 (diamond) and minesite station 3 (square), the adjusted mean monthly temperature at Entrance (inverted triangle), Robb (dot) and Yellowhead Lookout (triangle); average monthly temperature during 1930 - 1961 at Entrance (full line, no symbol): 1972 summer precipitation for Entrance (column 1), Robb (column 2), Yellowhead Lookout (column 3), control station 1 (column 4) and minesite station 3 (column 5); long-term precipitation for Entrance, Robb and Yellowhead Lookout (dashed line).

Thus, precipitation for June to September 1972 for the permanent recording stations was above average for June to September, average for July and below average for August. Overall, the study area received an average amount of precipitation throughout the summer. The long-term record of mean monthly temperatures recorded at Entrance shows that temperatures recorded in the study area were average for June and July, significantly above for August and significantly below average for September.

The climatic records taken in the study area are therefore considered to be typical of the summer climate of the region.

Comparison of temperature and precipitation data within the study area

Table 4.5 and Figure 4.4 show the monthly mean temperature, the monthly maximum and monthly mean minimum for the climatic stations for June, July and August and for control station 1 and minesite station 3 for September. The monthly mean temperatures of the control stations are similar for June and July and differ only by 0.7°C for August. Monthly mean temperatures for minesite stations differ by up to 1.1°C and are generally higher than the control station monthly means. Control station 1 has the highest maximum and lowest minimum temperatures for the entire period. The mean monthly maximum temperatures for the minesite stations are consistently lower than those of the control areas and the mean monthly minimum temperatures consistently higher. Generally then, the ambient air temperature in the minesite was warmer by 1°C than that of the control areas. Control station 2 was warmer than control station 1 and minesite station 3 was warmer than minesite stations 2 and 5.

The control areas thus exhibit greater ranges of monthly temperature than the minesite. To simplify further discussion control station 3

Table 4.5. Mean, mean minimum and mean maximum monthly temperatures (in°C) for micro-climatic stations in the study area

	June			July			August			September		
Station	Mn	M	Mx	Mn	M	Mx	Mn	M	Mx	Mn	M	Mx
C1	2.8	7.2	11.6	4.4	9.5	14.5	7.4	13.4	19.5	-4.4	-0.6	3.2
S2	3.9	6.8	9.7	6.3	10.7	13.7	9.8	14.5	19.2	-	-	-
S3	4.8	7.5	10.2	6.3	10.5	14.5	9.5	14.4	19.4	-3.1	0.4	3.8
C2	3.6	7.3	11.0	5.2	9.5	13.7	8.6	14.1	19.6	-	-	-
S5	4.2	7.5	10.7	5.4	9.3	13.3	8.8	13.7	18.6	-	-	-

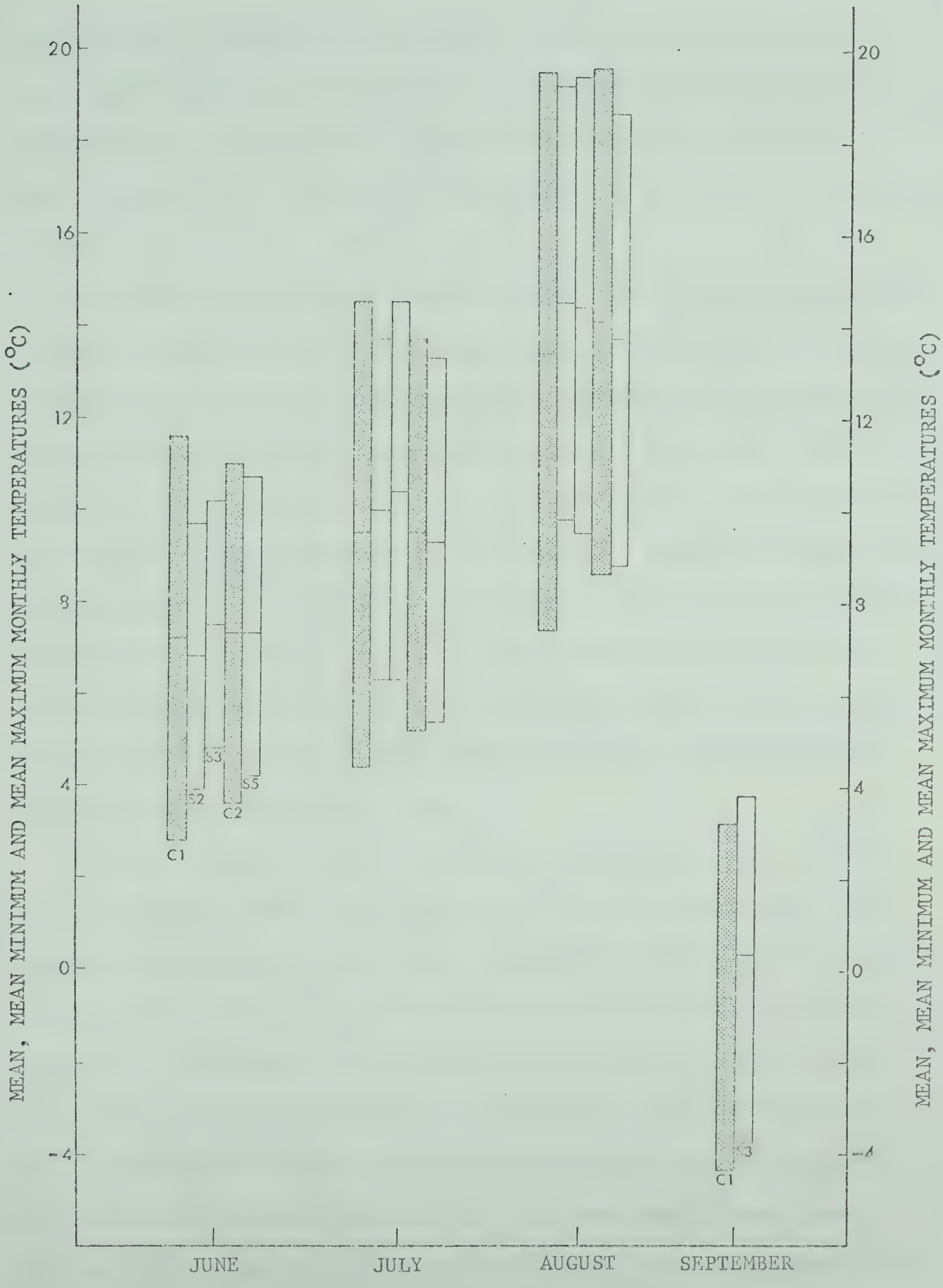


Figure 4.4. Mean, mean minimum and mean maximum monthly temperatures at each of the microclimatic stations in the study area.

will be used to represent the minesite. Figure 4.5 shows the mean, minimum and maximum daily temperatures for control station 1 and minesite station 3. Generally the control area has higher maximum and lower minimum so that the range of temperature is greatest in the control areas.

The minesite has a lower albedo than the control area and therefore it might be anticipated that air temperatures within the minesite would be higher than the control area during the day and cooler than the control area during the night because of the greater absorption of heat at the surface in the minesite during the day and greater re-radiation of heat from the surfaces at night in the minesite. Figure 4.6 shows the surface temperatures and percent of possible sunshine at control station 1 and minesite station 3. Figure 4.6 shows that for sunny days the surface temperature in the minesite is generally higher than the control area and that the reverse is true on overcast days. The temperature differences are not generally large.

Figure 4.7 shows the air temperature in the control area and minesite on two calm, clear, sunny days and two windy, overcast days. On bright, sunny, and calm days the air temperature at the control station is warmer during the day and cooler during the night than the minesite. On overcast, windy days the air temperature is slightly cooler at the control area during the day but the minesite is warmer throughout the night. The daily fluctuations of temperature are therefore greater in the control area than in the minesite. The mean monthly and diurnal fluctuations in temperature are contrary to what would be expected from the difference in the surface albedo at the control area and the minesite.

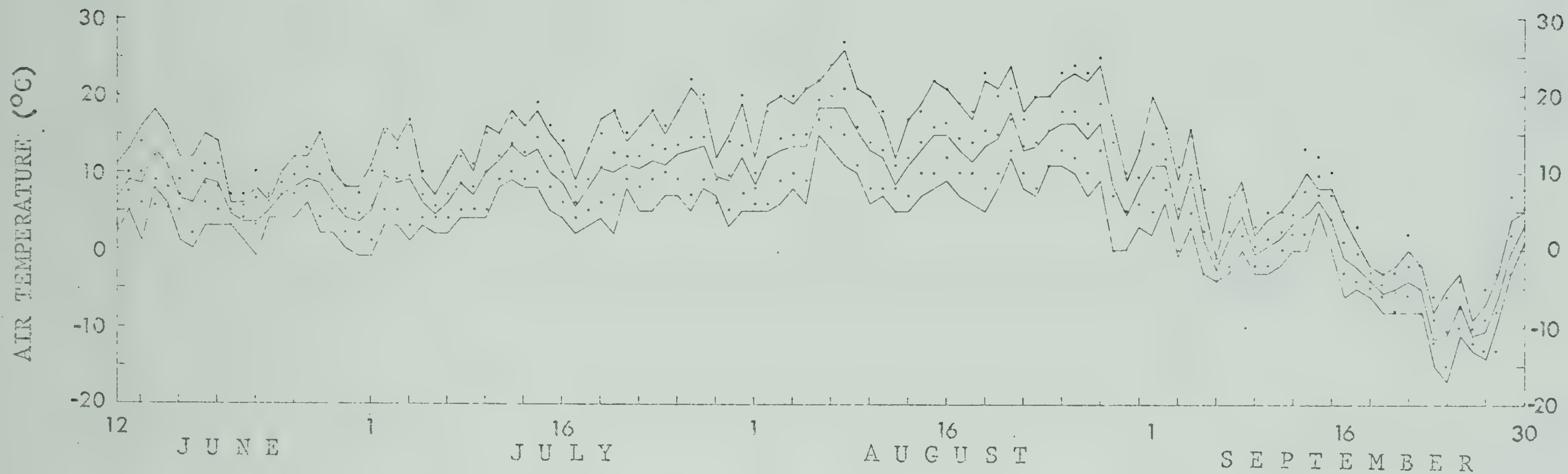


Figure 4.5. Mean, minimum and maximum daily temperatures for control station 1 (full line) and minesite station 3 (dots).

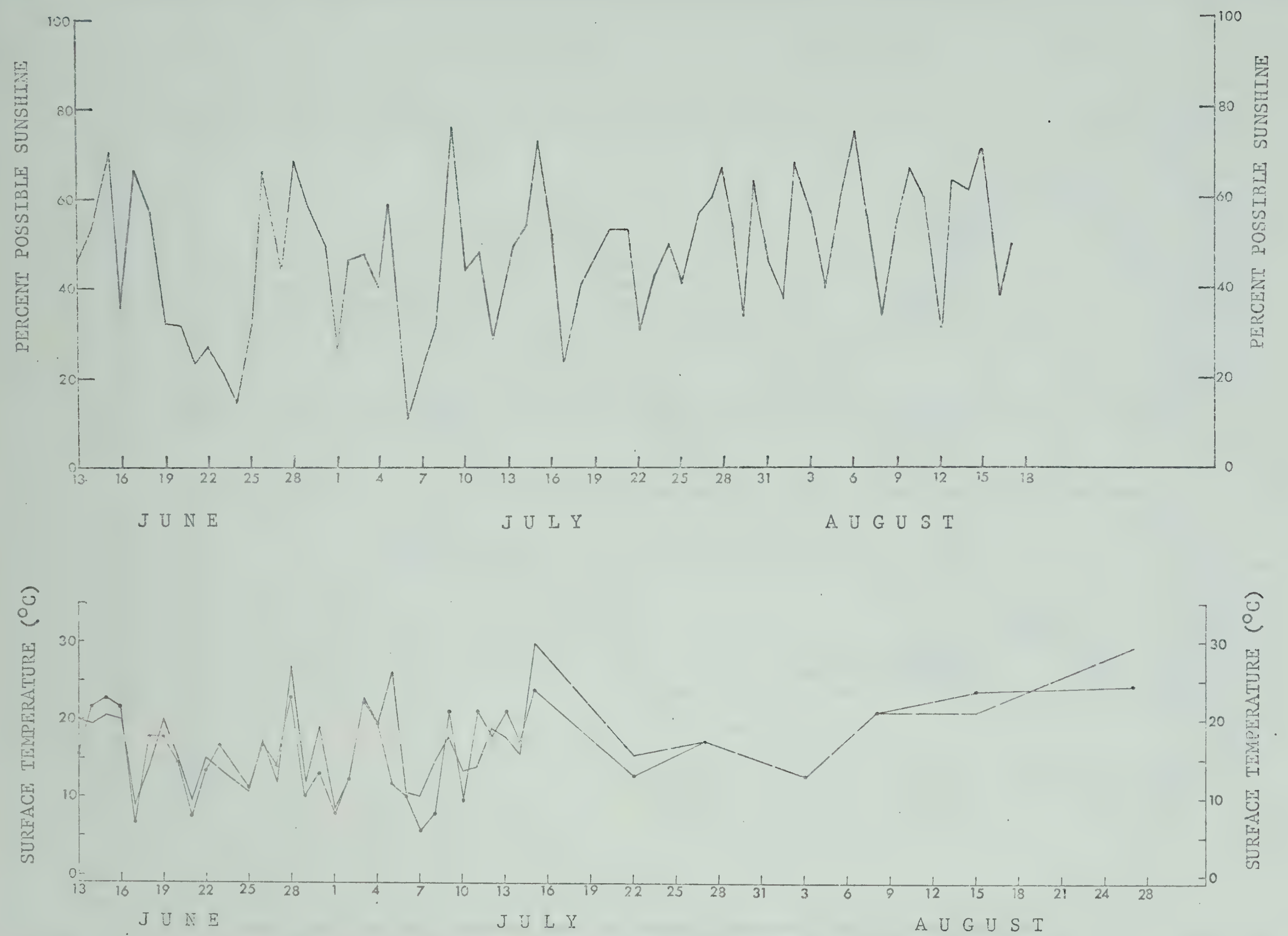


Figure 4.6. Percentage possible sunshine and surface temperatures at control station 1 (full line) and mine-site station 3 (full line and symbol). Measurements made at 1200 hours; dashed line of control station indicates data not measured.

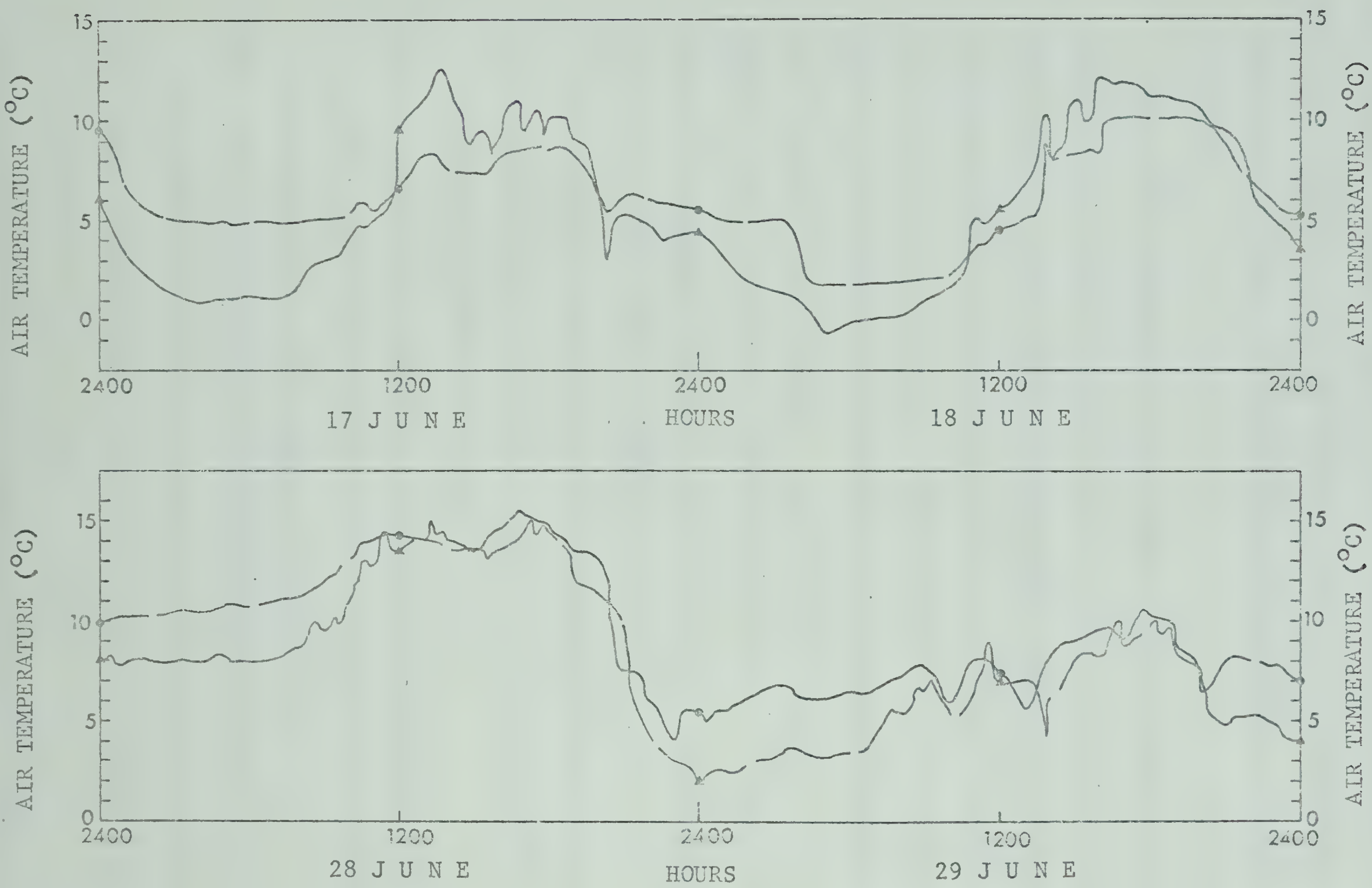


Figure 4.7. Air temperature in the control area (triangle) and minesite (dot) on two calm, clear, sunny days (upper diagram) and two windy, overcast days (lower diagram).

Heat is transferred into and out of the soil by the movement of air, water, and water vapour so that soil with a high permeability will warm and cool more rapidly than soil with a low permeability. It was established in Chapter III that the spoil materials are highly permeable.

The soil temperature profiles show that the minesite responds readily to the influx of heat or cold and that the control area responds more slowly, and that the soil temperature gradient in the minesite area is less pronounced than in the control area. Thus, the minesite is warmer than the control area at night because the heat accumulated deep in the spoil material of the minesite is released during the night and warms the air in the minesite: cold air is not ponded in the minesite whereas in the control area the vegetation tends to inhibit the mixing of warm air with cold air close to the surface. Hence the diurnal temperature regime shown in Figure 4.7.

The main conclusions from the temperature discussion are:

(1) The differences between the temperature in the control area and in the minesite average 1 to 3°C.

(2) The control sites have a greater variation in temperature with a higher temperature than the minesite during mid-day and a cooler temperature than the minesite during the night.

(3) Surface temperatures are generally higher in the minesite than in the control area and this can be attributed to the lower reflectivity of the minesite's surface and greater mixing of air close to the surface.

(4) Soil temperatures in the minesite are generally higher than in the control area and are warmer at depth than in the control area. Soil temperatures in the minesite show that the soil at depth in the

minesite warms and cools much more rapidly than the soil at depth in the control area.

(5) Soil temperatures rise and fall more rapidly in the minesite area than the control area and this may be attributed to greater permeability, high infiltration capacity and high transmissibility of the spoil materials.

(6) Ground surface temperatures within the minesite are not sufficiently high to damage plants.

Precipitation

Little difference in amounts of rainfall at each station was observed. The amounts and dates of rainfall recorded at control station 1 are shown in Figure 4.8.

Wind

It was not possible to measure wind speed continuously as instruments and a power supply were not available. Periodic measurements of wind speed were made with a portable anemometer and the wind speeds measured in the minesite correspond to the measurements made by Dillon (1972) at the minesite at Luscar. The minesite at Luscar is similar to the minesite in the study area and the wind speeds recorded there have been used an an index of wind speed in the study area. In the study area the measurements of wind speed made within the minesite are consistently higher than those made at control stations 1 and 2.

The discussion so far indicates that there is little significant difference in temperature and summer precipitation between the control area and the minesite. To extend the discussion further, temperature, precipitation, wind speed and surface albedo will be tied together in a discussion of potential evapotranspiration.

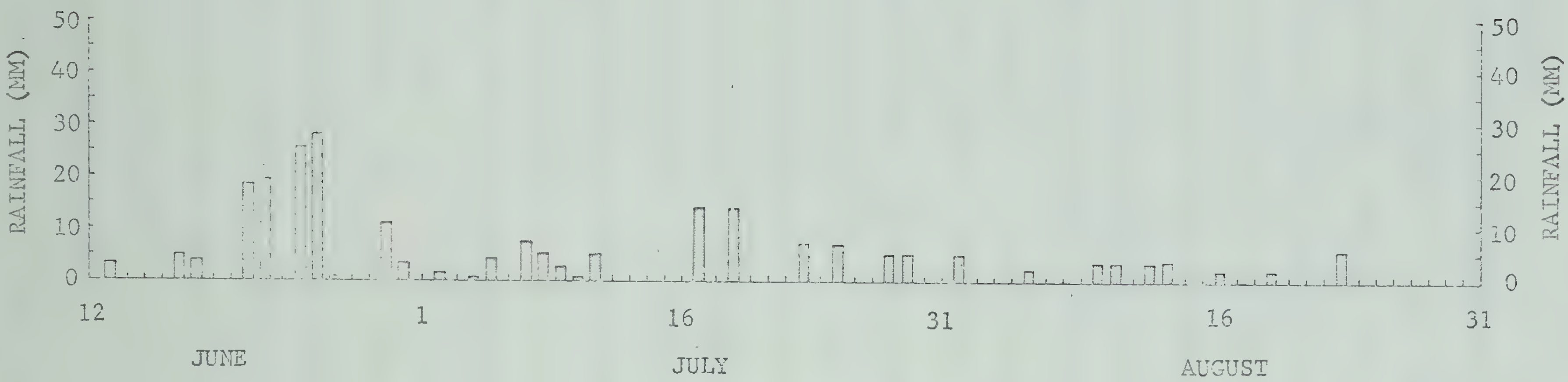


Figure 4.8. Rainfall at control station 1.

Potential evapotranspiration

Daily values of potential evapotranspiration were calculated for the period June 12th to August 17th for each of the stations in the study area using Penman's (Penman, 1963) and Christiansen's (Christiansen, 1966) methods. Figure 4.9 shows the total potential evapotranspiration for each of the stations in the study area. The control stations have significantly lower potential evapotranspiration than the minesite stations and control station 1 and minesite station 3 show the greatest differences. The daily values for control station 1 and minesite station 3 are shown in Figure 4.10. (The values of potential evapotranspiration for the Luscar site was supplied by T. Dillon and are based on the Christiansen method). The figures show that the methods give comparable results and that potential evapotranspiration is consistently higher in the minesite than in the control area.

Figure 4.11 shows the potential evapotranspiration for each station for two overcast, cool, calm days and two sunny, warm and windy days and the corresponding values at the Luscar site. Surface albedo and wind speed are the two elements identified so far as being significantly different in the minesite and the control area and the figure shows that air temperature at each station is not significantly different but the wind speed varies considerably. Thus, the differences in potential evapotranspiration may be attributed to differences in surface albedo and wind speed. Figure 4.12 shows the potential evapotranspiration for the same periods as Figure 4.11 using Penman's method but with various values of surface albedo (r). The effect of r on potential evapotranspiration for each site is relatively small.

Figure 4.13 shows the cumulative potential evapotranspiration for

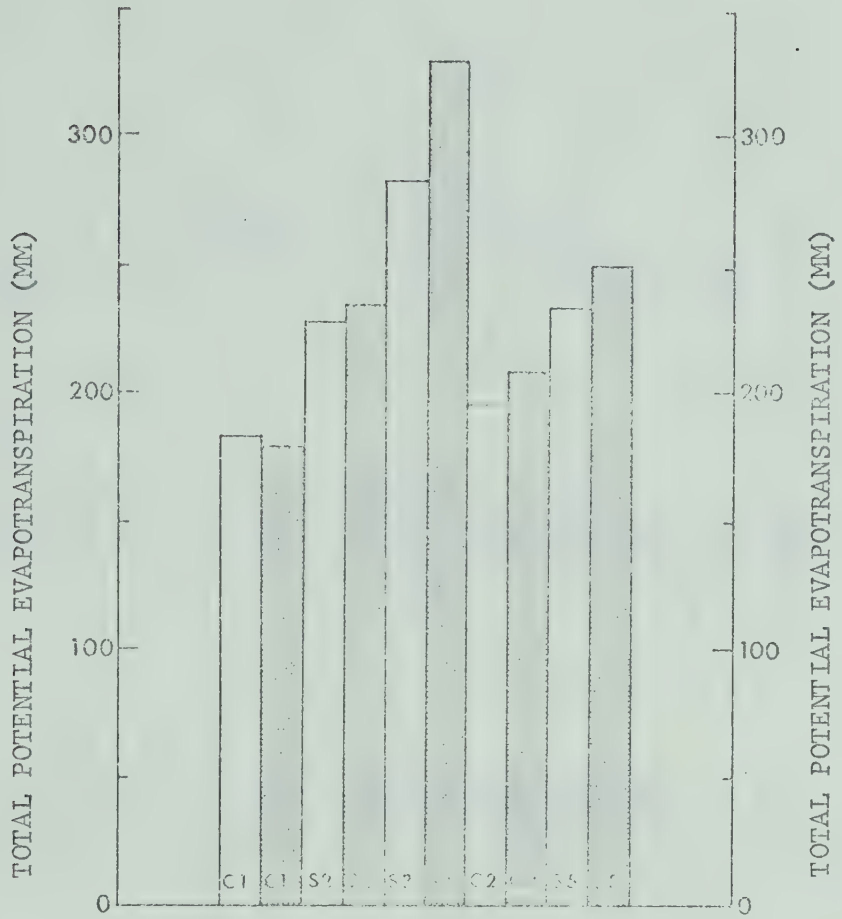


Figure 4.9. Total potential evapotranspiration for each of the stations in the study area. Open column was calculated using Christiansen's method and shaded column was calculated using Penman's method.

Figure 4.10. Daily values of potential evapotranspiration for control station 1 and minesite station 3 using Penman's and Christiansen's methods and daily values for Luscar using Christiansen's method. Column sequence from left to right is: control station 1 by Christiansen's method; minesite station 3 by Christiansen's method; control station 1 by Penman's method; minesite station 3 by Penman's method; and Luscar by Christiansen's method.

Figure 4.11. Potential evapotranspiration for each microclimatic station for two overcast, cool, calm days (21 June and 6 July) and two sunny, warm, windy days (15 July and 6 August) and the corresponding values at the Luscar site. Shaded column was calculated by Christiansen's method; open column was calculated by Penman's method; horizontal hatchure is value for Luscar which was calculated by Christiansen's method.

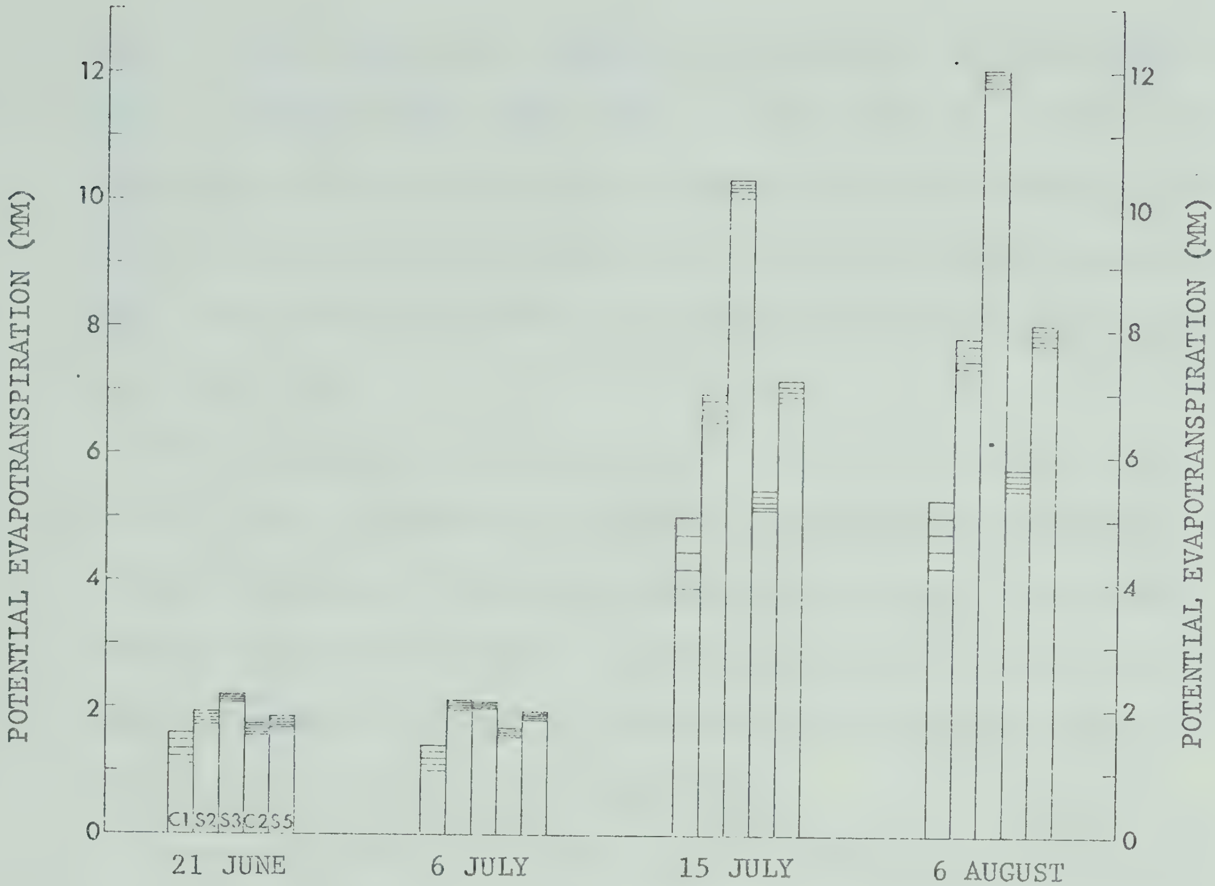


Figure 4.12. Potential evapotranspiration for the same periods as Figure 4.11 using Penman's method with values of surface albedo (r) as follows: control station 1 - 10. 15, 20, 25 and 30%; minesite station 2 - 8, 19, 12, 14 and 16%; minesite station 3 - 5, 6, 7, 8, and 10%; control station 2 - 7, 8.5, 10, 11.5 and 13%; minesite station 5 - 7, 8, 10, 11.5 and 13%. Lowest value of r gives highest potential evapotranspiration; highest value of r gives lowest potential evapotranspiration.

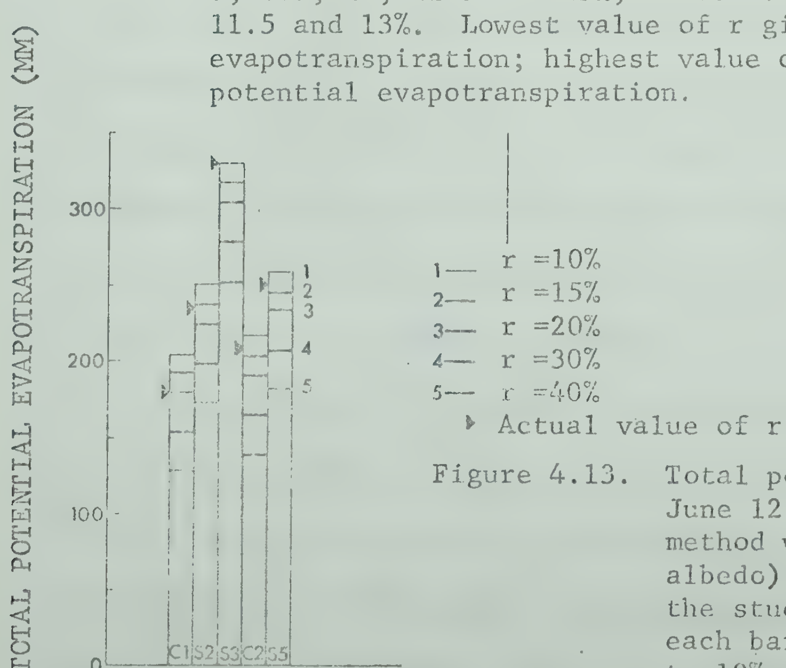


Figure 4.13. Total potential evapotranspiration for June 12 to August 17 using Penman's method with various values of r (surface albedo) and the estimated values of r in the study area. Top horizontal line in each bar (C1 - S5) has a value of r equal to 10%; second horizontal bar r = 15%; third horizontal bar r = 20%; fourth horizontal bar r = 30%; bottom horizontal bar r = 40%.

June 12th to August 17th using Penman's method with various values of r and the estimated actual values of r in the study area. Significant differences still arise even if the value of r used is identical for each station and hence the difference in potential evapotranspiration may be attributed to the difference in wind speed within the minesite and control area.

The potential evapotranspiration is an index of the amount of moisture that is required for optimal plant growth and evaporation under various conditions of temperature, humidity and wind. Thus if the values of cumulative potential evapotranspiration are compared with the amount of moisture supplied to the study area as precipitation, an indication of moisture stress is obtained.

Figure 4.14 shows cumulative potential evapotranspiration for control station 1 and minesite station by Penman's and Christiansen's methods and cumulative precipitation for the period June 12th to August 17th. Where the cumulative precipitation curve is above the cumulative evapotranspiration curve, moisture for optimal plant growth is surplus and where the curve if below the cumulative evapotranspiration curve moisture is deficient. Thus from Figure 4.14 it is apparent that a more pronounced moisture deficiency exists within the minesite. The period for which there is a moisture deficiency is also longer at minesite station 3 than at control station 1.

Obviously not all rainfall is retained at the surface for plant growth. No runoff was observed during the period June 12 to August 17 so that water loss from the soil was by percolation and evapotranspiration alone. Unfortunately soil moisture was not sampled in the study area so that it is not possible to determine the proportion of rainfall

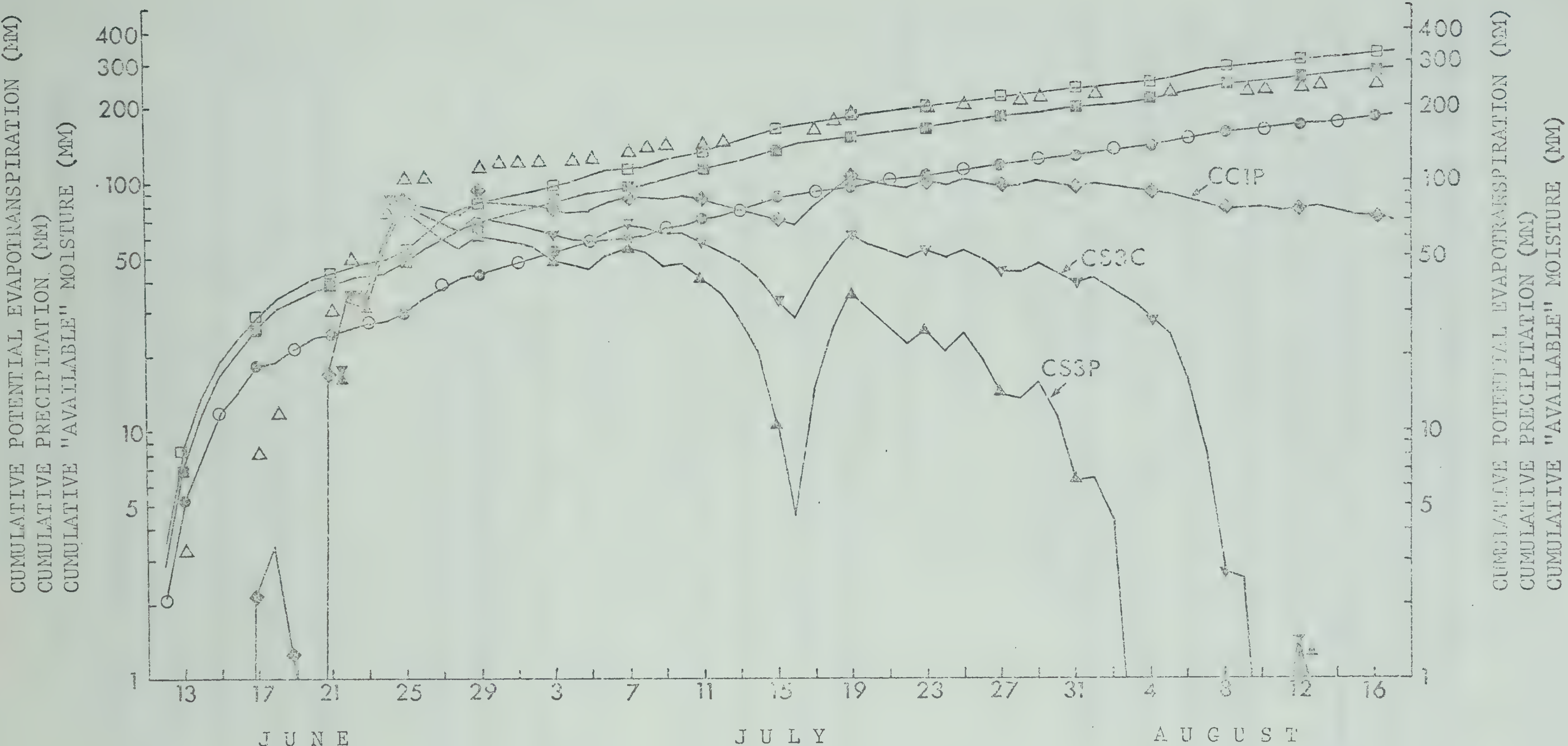


Figure 4.14. Cumulative potential evapotranspiration for control station 1 and minesite station 3 using Christiansen's method (full line and solid dot for control station 1; full line and solid square for minesite station 3) and Penman's method (open circle for control station 1, value almost identical to Christiansen's control station 1 value; full line and open square for minesite station 3): cumulative precipitation (open triangle), and cumulative available moisture (CC1P, CS3C and CS3P) (see text for definition) for control station 1 and minesite station 3 for the period June 12th to August 17th.

retained in the soil of the control area and spoil of the minesite. However, it was demonstrated in Chapter III and in the temperature section of this chapter that the spoil is highly permeable and with low organic matter so that water loss by percolation is probably significant. Figure 4.14 also shows an index of available moisture which is defined as the accumulated daily precipitation less the daily accumulated evapotranspiration. Thus corrected cumulative moisture (C) equals the sum of accumulated daily rainfall (CP) minus accumulated daily potential evapotranspiration (CPE) or

$$C = \sum_{\text{June } 12}^{\text{Aug. } 17} (CP - CPE)$$

where C cannot be less than 0.00 and

CC1P = cumulative available moisture at control station 1 using Penman's method to calculate potential evapotranspiration. (CC1P = CC1C as values for potential evapotranspiration for control station 1 using Penman's method are practically identical).

CS3P = cumulative available moisture at minesite station 3 using Penman's method to calculate potential evapotranspiration.

CS3C = cumulative available moisture at minesite station 3 using Christiansen's method to calculate potential evapotranspiration.

These curves then give an index of available moisture assuming that no moisture is lost to percolation. Figure 4.14 shows that

(1) Potential evapotranspiration for control station 1 using Penman's method and Christiansen's method are practically identical.

(2) Potential evapotranspiration for minesite station 3 using Penman's method and Christiansen's method are similar.

(3) Cumulative precipitation exceeds the cumulative evapotranspiration at control station 1 from June 21 to August 17 whereas at minesite station 3 cumulative precipitation exceeds cumulative evapotranspiration for a shorter period from June 22 to August 5.

(4) Soil moisture storage at control station 1 is estimated at 26 mm so that the cumulative available moisture curve for control station 1 shows that moisture for optimal plant growth (potential evapotranspiration curve) is deficient at control station 1 for July 13 to July 18 and July 20 to August 17. The curve of potential evapotranspiration approximately parallels the cumulative available moisture curve so that adequate moisture for plant growth is available. Soil moisture storage at minesite station 3 is estimated at 12 mm so that the cumulative available moisture curves CS3P and CS3C indicate moisture deficiency for June 14 to June 24, June 26 to August 17 and June 16 to June 24, June 30 to August 17 respectively. The magnitude of the deficiency is given by the difference between cumulative potential evapotranspiration and the cumulative available moisture curve so that the minesite has a far greater moisture deficiency and maintains that deficiency for much longer that the control area. Thus, the amount of moisture maintained in the soil of the control site and spoil of the minesite are significantly different.

<u>Summary</u>

The spoil materials react more rapidly to the influx of heat or cold than the control area and hence have more uniform soil temperatures at depth. The highly permeable spoil behaves as a heat sink during the day and releases heat during the night and thus moderates the diurnal temperature regime of the minesite.

It is apparent that the air, surface, and soil temperature regimes of the minesite and the control area are not significantly different.

Potential evapotranspiration calculated by two methods give similar results.

Potential evapotranspiration is consistently higher in the minesite than in the control area.

The albedo of the minesite and the control area are not sufficiently different to account for the large differences in potential evapotranspiration.

The potential evapotranspiration exceeds the amount of moisture supplied by rainfall and a moisture deficiency was present for most of the study period.

Differences in wind speed are significant and account for the differences in potential evapotranspiration between control station 1 and minesite station 3.

The moisture deficiency is more pronounced and exists for longer periods in the minesite.

CHAPTER V

VEGETATION AND HABITAT

The type and distribution of vegetation in the study area will be discussed and related to geologic conditions in the study area.

Vegetation

Plants in the minesite are isolated, widely separated, and difficult to map and to estimate the ground cover. The communities identified give a semblance of local groupings with one or two plants as dominant species. Table 5.1 lists the communities identified and the percent of ground covered.

Tables 5.2 and 5.3 list plants identified in undisturbed sites within the minesite and on spoil material in the minesite.

The distribution of plant communities and percentage of plant cover is given in Figure 5.1 (in pocket).

The areas of undisturbed vegetation in the minesite resemble the control area vegetation. Vegetation in disturbed areas consists of isolated, individual plants or small individual plant mats.

Plants within the minesite have the following characteristics.

(i) Plants are frequently low, prostrate, decumbent, spreading, creeping, acaulescent or caespitose.

(ii) Plants are frequently matted with a dense growth of overlapping leaves.

(iii) Plants frequently have perennial rootstocks, annual roots, rhizomes, large tap roots, dense fibrous root mats and spreading- and deep--penetrating roots.

(iv) Plants frequently reproduce vegetatively.

Table 5.1. Plant communities and percentage ground cover in the minesite

Community		Percent cover
A1	*Crepis nana*	0.01 - 1.0
A	*Crepis nana* / grass	1 - 5
C	grass / *Achillea millefolium*	1 - 10
C1	grass / *Achillea millefolium*	10 - 50
C2	sedge / *Achillea millefolium*	10 - 50
B	*Trifolium* sp. / *Taraxacum officinale*	50 - 80
E	*Equisetum* sp. / grass	10 - 40
E1	*Equisetum* sp. / grass	40 - 70
D	*Alnus crispa*	80 - 100
N	*Picea engelmanii* / *Pinus contorta* / *Alnus crispa* / grass	complete groundcover

Table 5.2. Plants found in undisturbed sites within the minesite

Scientific name	Common name
Gramineae sp.	grass species
Arctosaphylos uva-ursi (L.) Spreng.	common bearberry, kinnikinnick
Arctostaphylos rubra (Rehder & Wils.) Fern.	alpine bearberry
Epilobium angustifolium L.	fireweed, great willow-herb
Alnus sinuata (Regel) Rydb.	alder
Betula glandulosa Michx.	dwarf birch
Juniperus horizontalis Moench	creeping juniper
Rosa sp.	rose
Salix sp.	willow
Picea engelmanii Parry	Engelmann spruce
Picea glauca (Moench) *Voss*	white spruce
Pinus contorta Louden var. *latifolia* Engelm.	lodgepole pine

Table 5.3. Plants found growing in the minesite on spoil material

Scientific name	Common name
Achillea millefolium L.	common yarrow
Aster sp.	aster
Androsace chamajasme Host	sweet-flowered androsace
Astragalus eucosmus Robins.	milk vetch
Botrychium minganense Victorin.	mingan grape-fern
Campanula rotundifolia L.	bluebell, harebell
Cirsium vulgare (Savi) Airy-Shaw	bull thistle
Crepis nana Richards.	hawksbeard
Delphinium glaucum S. Wats.	tall larkspur
Dryas drummondii Richards.	yellow dryad
Dryas integrifolia M. Vahl	white dryad
Epilobium angustifolium L.	fireweed, great willow herb
Epilobium latifolium L.	willow herb
Equisetum arvense L. or *E. sylvaticum*	horsetail, scouring rush
Galium boreale L.	northen bedstraw
Gentianella amarella (L.) Borner ssp. *acuta* (Michx.) J.M. Gillett	felwort
Haplopappus sp.	..
Heracleum lanatum Michx.	cow-parsnip
Leguminosae sp.	
Lychnis apetala L.	campion
Mertensia paniculata (Ait.) G. Don	tall mertensia
Oxytropis campestris (L.) DC.	late yellow loco-weed
Ranunculus acris L.	tall buttercup
Senecio canus Hook.	prairie groundsel
Solidago decumbens Greene	goldenrod
Taraxacum officinale Weber	common dandelion
Trifolium pratense L.	red clover
Trifolium repens L.	white clover, Dutch clover
Zygadenus gramineus Rydb.	death camus
Alnus sinuata (Regel) Rydb.	alder
Potentilla fruticosa L.	shrubby cinquefoil
Juniperus communis L.	ground juniper
Rosa woodsii Lindl. and *R. acicularis* Lindl.	common wild rose and prickly rose
Rubus strigosus Michx.	wild red raspberry
Salix sp. (probably *S. scouleriana* Barratt)	willow
Populus balsamifera L.	balsam poplar
Lycoperdon perlatum Pers.	puffball

(v) Plants die back to rootstocks or perennial stocks and reproduce by underground rhizomes.

(vi) Plants grow only in places protected from the wind such as the lee sides of boulders and logs and in depressions and hollows. The plants also grow away from the prevailing wind; i.e., growth extension with wind direction.

(vii) Plants are adapted to rocky, gravelly, sandy, moisture deficient wind-swept habitats typical of high alpine regions.

(viii) Plants are more frequently found at the break in slope at the base of spoil piles.

(ix) In the control area and the minesite plants are abraded and gnarled by wind-borne particles of snow or rock (Plate 5.1). Figure 5.1 shows the distribution of trees killed and damaged by wind-borne particles. Figure 5.2 shows the distribution of snow and the source area for wind-blown snow and rock particles.

It was also noted that:

(i) plant seeds settle only in places protected from the wind;

(ii) many plants in the minesite produce seeds in profusion and many of the seeds have large feathery pappi which makes them susceptible to wind transport;

(iii) steep slopes of spoils lack vegetation and the vegetation that has established on the slopes is adapted to annual inundation by fine-grained rock particles.

<u>Vegetation and geologic aspects of habitat</u>

Spoil materials, except coal, are fertile and will support vegetation, but steep slopes limit vegetation by the rapid downslope movement

Table 5.4. Location of snow sampled, depth of snow cover, water equivalent and density of snow in control area and minesite March 1972 and January 1973

		Location		Depth of snow cm	Water equivalent cm	Density %	Comments
March 1972	Control area	Haul road below minesite	(1)	78.0	15.7	20.1	Exposed; low vegetation
		Near C1	(2)	147.0	33.5	22.8	Sheltered; in trees
		Near C1	(3)	107.0	33.0	30.8	Sheltered; in trees
	Minesite	Near S2	(4)	12.5	2.06	16.5	Exposed; windswept
		Near S2	(5)	38.3	7.56	19.8	Powdery snow; windswept
		Near S3	(6)	20.3	1.75	8.7	Powdery snow; windswept
		Near S3	(7)	129.0	34.8	27.0	Snowbank
		Near S3	(8)	59.0	17.8	30.2	Snowbank
		Near C2	(9)	48.0	10.2	21.3	Snowbank
		Near C2	(10)	23.1	2.28	9.9	Powdery snow
Jan. 1973	Control	Near C1	(11)	33.3	10.2	30.8	Sheltered; in trees
	Mine-site	Near S3	(12)	0.0	0.0	0.0	Exposed; windswept

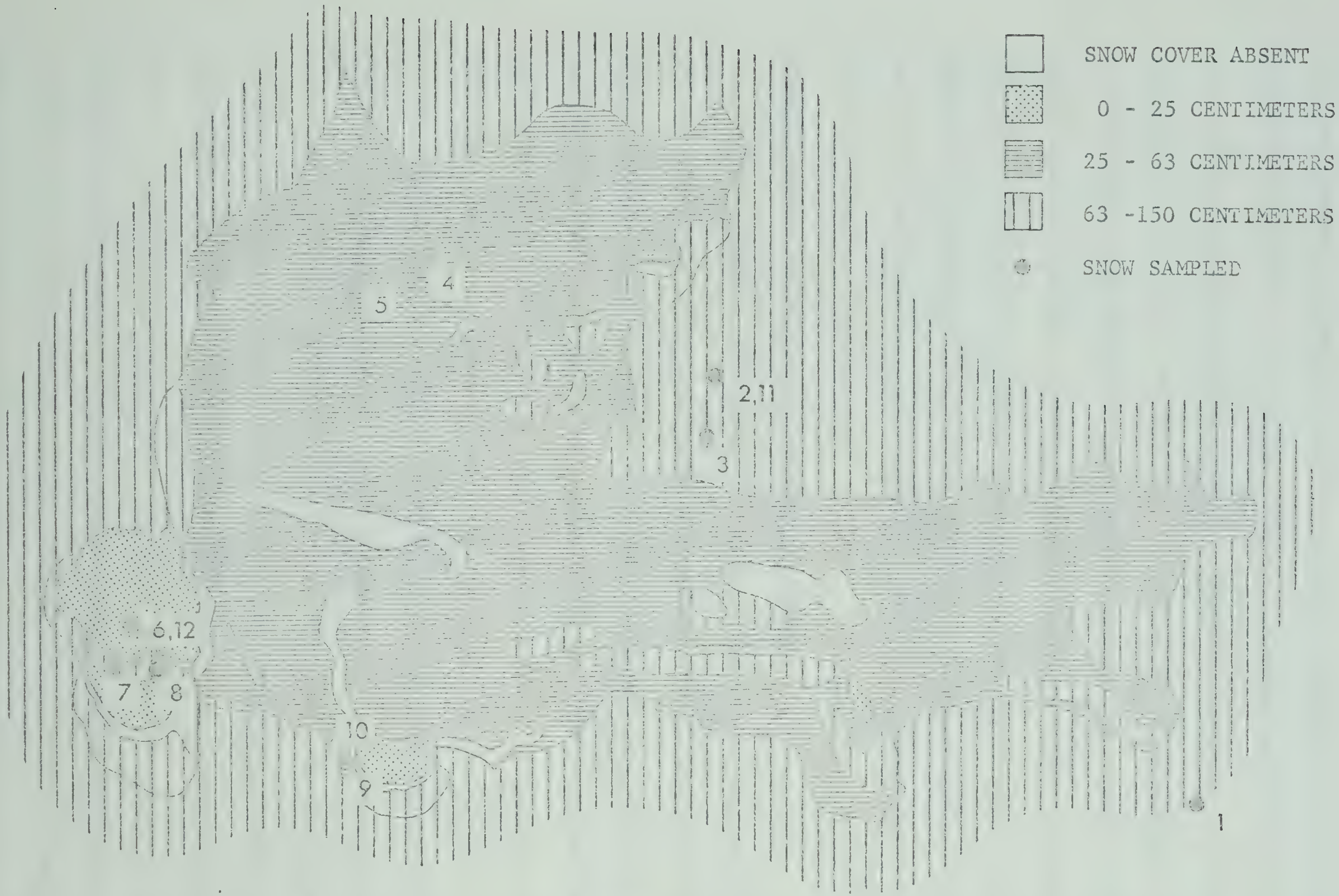


Figure 5.2. Distribution of snow cover in the study area March 1972; minesite had no snow cover January 1973, control area had 33 cm (10.2 water equivalent) January 1973.

of frost-shattered fine-grained material and inundation by wind-transported fine-grained rock debris. Figure 5.1 shows spoil pile slopes are practically devoid of vegetation. Vegetation on the flat surfaces of spoil is limited by the abrasion of vegetation by wind-borne particles of rock and by the deflation pavement created by the removal of fine-grained rock particles. Where these rock particles have accumulated below the minesite the understory vegetation has been buried and growth retarded. Groundwater in the minesite has a pH of about 8, is pure and supports relatively luxuriant vegetation where the groundwater discharges at the surface of the minesite.

Vegetation and microclimatic aspects of habitat

It was shown in Chapter IV that the temperature regimes of the control area and the minesite are not significantly different, that the summer precipitation is not significantly different and that the albedo has little effect on the surface temperature and the potential evapotranspiration of the minesite and the control areas. Potential evapotranspiration for the control area and the minesite, moisture retained at the soil surface and wind were shown to be significantly different. Table 5.4 shows the depth and water equivalent of snow measured during three snow surveys. Winter precipitation is the same in the minesite and the control areas but the snowfall in the minesite is considerably redistributed by wind (Plate 5.2, Figure 5.2). Thus large areas in the minesite do not retain snow cover and hence receive no soil moisture recharge from snowmelt. In places within the minesite that retain snow in snowdrifts the fine-grained dark-coloured rock particles that are blown with the snow form layers on top of and within the snowdrift. These layers reduce the albedo of the snow, promote the absorption ot

heat and therefore promote the ablation and melt of the snowpack. Thus the amount of moisture retained in the minesite from winter precipitation is significantly different from the control areas.

Effects of wind

The removal of snow cover allows vegetation on the minesite surface to be abraded by wind-borne particles of snow and rock, and dessicated by warm chinook winds. Plants in the minesite that die back to a rootstock therefore have a better chance of survival over winter.

Trees adjacent to the minesite have been damaged by wind-blown particles of snow and rock and exhibit an asymetrical shape with branches extending on the side of the tree protected from the prevailing wind. Some trees have been killed by wind-borne particles since mining operations ceased and have rotted at their base and have been blown down by storm winds from the west. The orientation of the fallen trees and the orientation of the flagging of branches is remarkably consistent and parallels the direction from which fine-grained rock particles are moved and deposited.

A number of the dead trees were cut and the growth rings examined. The annual growth rings show a marked eccentricity with the pith closest to the west-facing side of the tree. The three sections show a decrease in the eccentricity of the growth rings with increase in height so that the eccentricity is probably produced by abrasion by wind-borne particles.

Two vegetated pebble dunes shown in Figure 5.3 show orientations of 80 and 85 degrees which is consistent with the orientation of flagging, and stems that extend above the dense *Salix* mat on the dunes during the summer are killed off by abrasion and dessication during the winter. During the winter of 1972 - 1973 the three screens and screen

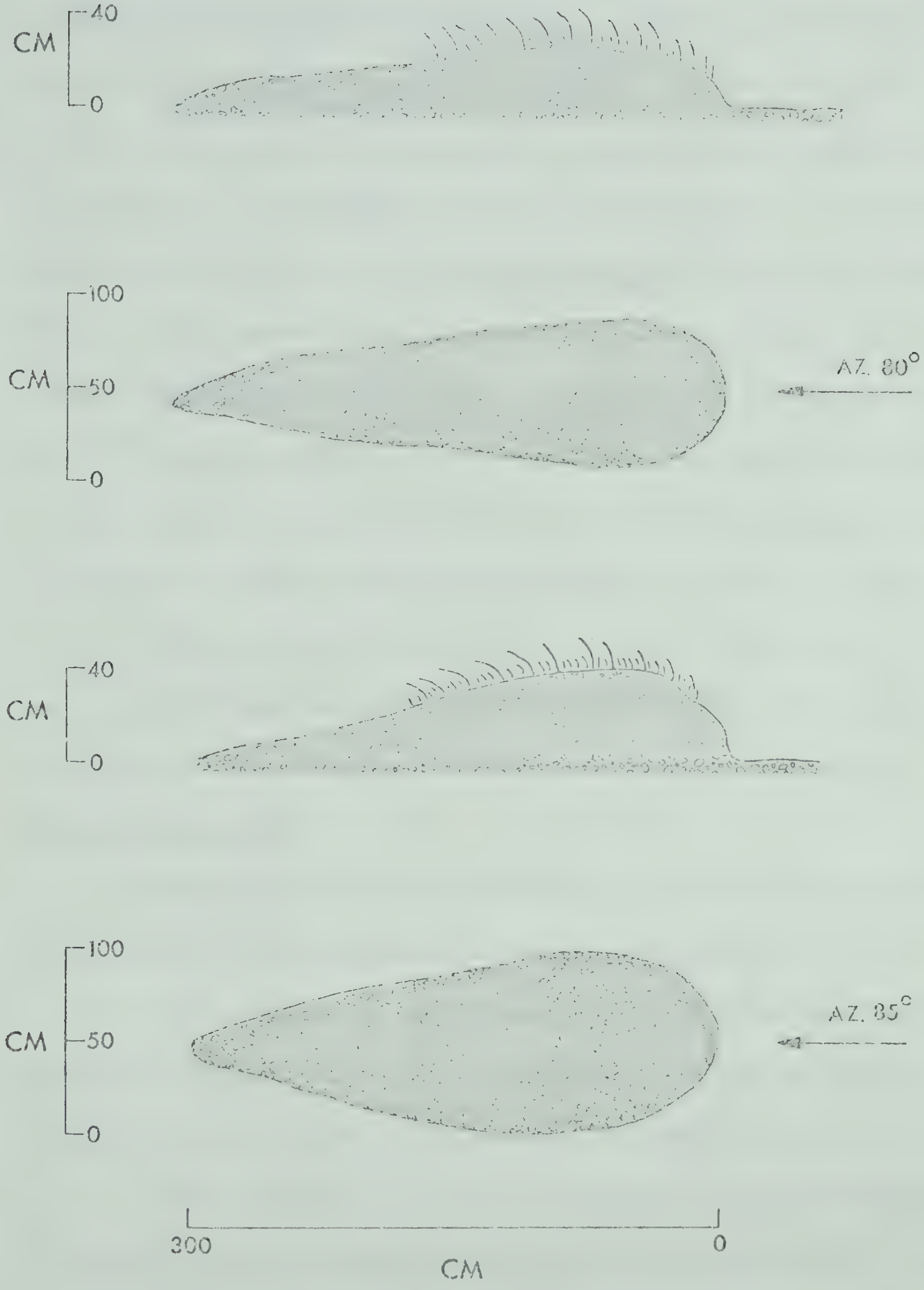


Figure 5.3. Two partially-vegetated pebble dunes in the study area near control station 2. Vegetation is <u>Salix</u> sp. which forms a dense mat close to the surface of the dune; annual growth above the mat is killed off during winter by abrasion and dessication.

stands in the minesite were displaced from 12 - 20 degrees from the vertical by storm winds (Plate 5.3). The four, 5 x 10 cm legs of each screen stand were embedded in 1 meter of coarse, compacted, angular rock of the spoil in the minesite. Considerable force would be required to displace these stands from the vertical and it is not surprising that winds in excess of 160 km/hr have been reported (Edmonton Journal, 1973). The screen stands were painted with a thick coat of white paint at the beginning of the field season and that paint was intact at the end of September 1972. By January 1973 the paint at the base of the screen stands on the west-facing side had been removed by wind-blown rock particles and the screen's west-facing side was pitted and scarred by the impact of wind-blown rock particles (Plate 5.4).

The winter storm winds in the study area thus blow from the west, are violent, persistent and damaging to plants.

Seed distribution

The summer and fall winds are also persistent and strong and have a considerable influence on seed distribution.

Geiger (1965, p. 47) gives an equation for the "probable flight path" of a seed (defined by assuming a seed has an equal probability of being above this path or below it). He states:

"Starting from the point of release with coordinates X = 0, Z = 0 cm, the probable flight path rises to a height of z = Z (vertex) and descends to the level of release (z = 0) at a distance of x = X (range in the direction of wind). The path is a parabola with the equation". (Geiger, p. 47).

$$Z = 0.477 \sqrt{\frac{4Ax}{pu}} - \frac{c}{u}x$$

where

A = austausch coefficient (gm cm^{-1} sec^{-1})

p = density of air (gm cm^{-3})

u = wind speed (cm sec^{-1})

x = height of release of seed (cm)

c = rate of fall of seed (cm sec^{-1})

If an air density of 0.0013 gm cm^{-3} is assumed the probable range (where $x \neq 0$) reduces to

$$X = 700 \frac{Au}{c^2}$$

where A and u are defined as above and c = rate of fall of seed (cm sec^{-1}) (dependant on seed shape, size and mass).

Figure 5.4 shows probable range of seed flight against wind speed for four seed types similar to seeds found within the study area. Most of the herbs and forbs produce feathery pappi and the flight path of these seeds will be similar to the achenes of dandelion shown in Figure 5.4. When wind speed is greater than 3 kilometers per hour the probable range of seed flight of seeds similar to dandelion exceeds the dimensions of the minesite. Seeds produced within the minesite will therefore tend to be blown out of the minesite by relatively gentle winds. This does not preclude seeding from the control area to the west of the minesite. Generally the vegetation cover increases from east to west in the minesite which probably reflects lower wind speeds at the west end of the minesite (shelter of vegetation; less fetch for wind) and less removal of seed from the area. At the east end of the minesite, where considerable fetch is available to the wind, higher winds are present, more seeds are removed from the minesite.

Seeds produced within the minesite with shorter probable range

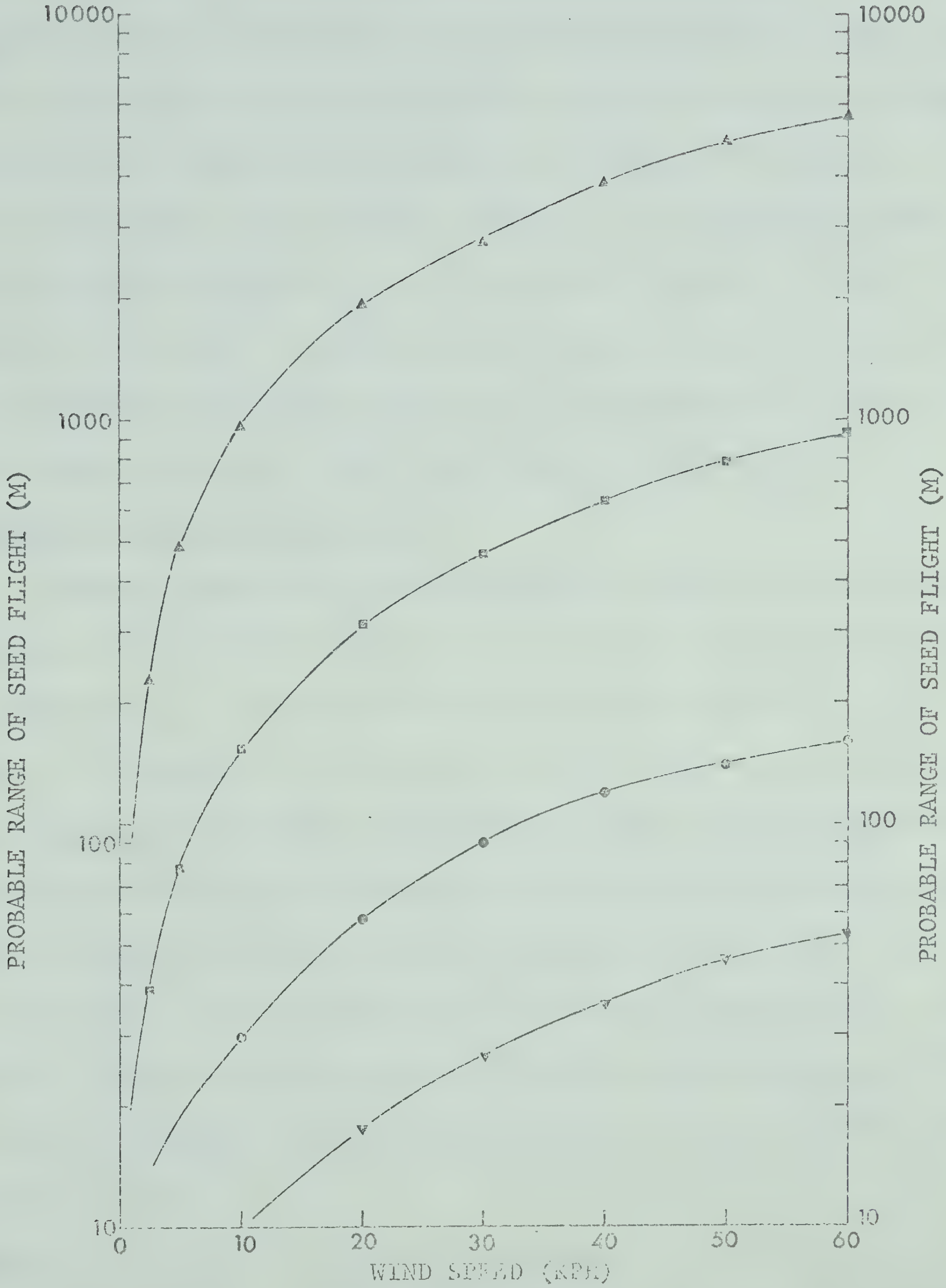


Figure 5.4. Probable range of seed flight for particular wind speeds with achenes of dandelion (Taraxacum officinale) (triangle), birch seed (Betula verrucosa) (square), spruce seed (Picea exelsa) (dot), and fir seed (Abies pectinata) (inverted triangle).

(shown in Figure 5.4) will fall within the minesite even at relatively high wind speeds. However the pebble deflation pavement of the minesite presents few seed catchment places compared to undisturbed vegetated ground and seeds may be repeatedly uplifted and transported. This offsets the higher rate of fall of the seed. Most seeds therefore eventually lodge in places protected from the wind and the azonal and isolated plant cover is a reflection of seed transport into the minesite, the high winds and moisture deficiency created primarily by high evapotranspiration and rapid percolation of soil water.

Infrared film and moisture stress

Healthy plants will show up as bright red on Kodak False-colour reflection infrared film and those under moisture stress will show up as reddish-brown. One roll of this film was exposed on one day in August on plants with known adequate moisture supply (groundwater seepare and springs) and plants established on spoil materials. Although no sequential photography was possible, plants with known adequate moisture supply photographed bright pink and on spoil materials plants photographed light pink- to pink-brown. Thus moisture deficiency in indicated for plants growing on spoil materials as would be expected from the plot of potential evapotranspiration and available moisture shown in Figure 4.14.

Summary

Generally the vegetation abundance in the minesite decreases from west to east and this may be attributed to the greater wind fetch which leads to higher winds at the east end of the minesite and therefore higher evapotranspiration, greater removal of snow and fine-grained rock particles, and greater abrasion of adjacent vegetation.

In the control areas, the established vegetation shelters the ground surface from wind which prevents removal of snow, reduces potential evapotranspiration and protects young plants from abrasion by snow and rock particles.

Plate 5.1. Young Engelmann spruce damaged on its west-facing side by wind-blown particles.

Plate 5.2. Wind redistributed snow at the east end of the minesite in March of 1972.

CHAPTER VI

CONCLUSIONS

It has been shown that the principle elements limiting natural revegetation are climatic rather than geological.

Geological

(1) The Luscar Formation from which the coal at Cadomin was extracted extends from Nordegg to northeast British Columbia and similar geological conditions will arise where coal is extracted by surface means anywhere along its length.

(2) Spoil piles are stable.

(3) The spoil surface weathers extremely rapidly by physical processes.

(4) No evidence of significant chemical weathering was observed.

(5) Runoff in the minesite is rare and little gullying has occurred.

(6) Groundwater seepage through spoil materials is rapid and the chemical and physical properies of the water after passage are not significantly changed.

(7) Spoil materials, except coal, are fertile and support vegetation but are highly permeable and do not retain much moisture close to the surface.

(8) The rapid downslope movement of finely comminuted rock material on steep spoil slopes inhibits revegetation.

Meteorological

(9) The air, surface and soil temperature regimes and summer precipitation of the minesite and control areas are not significantly different.

(10) High, persistent, year-round winds remove snow cover and fine-

grained rock material and these particles abrade vegetation in the minesite and the adjacent undisturbed vegetation.

(11) The high, persistent winds tend to remove seeds produced in the minesite.

(12) Potential evapotranspiration in the minesite is significantly higher in the control area.

(13) The natural revegetation of the abandoned minesite east of Cadomin is limited by the removal by wind of seed supplied to the area, the abrasion of vegetation on the minesite surface by wind-borne particles of rock and snow, and moisture deficiency created by high permeability of spoil materials, the removal of snow cover during winter by storm winds and chinooks, and the high summer evapotranspiration in the minesite which results from persistent winds over the minesite.

Revegetation of disturbed land

If artificial revegetation of disturbed land in the Alberta Foothills is to be successful moisture deficiency and wind velocity must be reduced. The moisture deficiency may be reduced by compacting spoil, deliberately drifting snow, and reducing evapotranspiration by reducing wind. Thus mixing organic material with surface spoil, the use of snow fences, shelter belts and the creation of a rough microtopography will encourage plant growth. However, care must be taken not to allow surface runoff because of the high potential erodability of spoil materials.

Future research

The study has provided a basis for future research which should include the following investigations.

(i) Determination of infiltration rates, percolation rates and soil moisture retention capabilities of various mixtures of spoil.

(ii) Determination of the effect of spoil compaction on infiltration rates, percolation rates and soil moisture.

(iii) Determination of an ideal water balance for minesites.

(iv) Determination of economic ways to reduce wind velocity over minesites.

(v) Determination of the effect of mixing organic materials with the surface spoil.

(vi) Determination of drought-resistant, abrasion tolerant and dessication-tolerant plants.

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F. 236 September 1975

LEGEND

COMMUNITY		PERCENT COVER
■	Areas devoid of vegetation	
A1	Crepis nana	0.01 - 1.0
A	Crepis nana / grass	1 - 5
C	grass / Achillea millefolium	1 - 10
C1	grass / Achillea millefolium	10 - 50
C2	sedge / Achillea millefolium	10 - 50
B	Trifolium / Taraxacum officinale	50 - 80
E	Equisetum sp. / grass	10 - 40
E1	Equisetum sp. / grass	40 - 70
D	Alnus crispa	80 - 100
N	Picea engelmannii / Pinus contorta / Alnus crispa / grass	
W	Picea engelmannii / Pinus contorta / Alnus crispa / grass wind damaged; wind-borne particles abrasion and dessication	
WT	Picea engelmannii / Pinus contorta killed off by wind-borne particle abrasion and dessication	

Figure 5.1. Plant communities and percentage ground cover in the minesite.